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OF THE
ROYAL AERONAUTICAL SOCIETY

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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NOTICES

Honorary Secretary

Mr. J. L. Pritchard has, at the request of the Council, agreed to act as Honorary Secretary of the Society and took up his duties on May 1st.

Elections

The following Members were elected at a Council Meeting held on April 21st :—

Associate Fellows.—Mr. H. Davies and Mr. J. H. Hartley.

Students.—Mr. J. L. Merrill, Flying Officer O. R. Piggott and Mr. T. Raftopoulos.

Foreign Member.—Lieut. E. A. Brunner.

Associate Member.—Mr. E. G. Richardson.

Mr. Denis McNab has been elected a Member of the Scottish Branch.

Committees and Representatives on Other Bodies

The following Members of Committees and Representatives on other bodies were nominated at a meeting of Council held on April 21st :—

Candidates Committee.

The Chairman and Vice-Chairman (*ex-officio*), Professor L. Bairstow, Major T. M. Barlow, Major B. C. Carter, Professor B. Melvill Jones, Major Mayo, Professor A. J. Sutton Pippard, Major G. H. Scott, Mr. T. O. M. Sopwith and Mr. C. W. Tinson.

Finance Committee.

The Chairman and Vice-Chairman (*ex-officio*), Mr. Griffith Brewer, Mr. C. R. Fairey, Mr. A. E. Turner (Treasurer) and Mr. P. F. Walsh.

Air League of the British Empire.

Colonel The Master of Sempill.

Joint Standing Committee with the Society of British Aircraft Constructors and the Royal Aero Club.

The Chairman and Vice-Chairman (*ex-officio*), Professor L. Bairstow, Major-General Sir W. S. Brancker, Wing Commander T. R. Cave-Browne-Cave and Mr. W. O. Manning.

British Engineering Standards Association Aircraft Committee.

Major R. H. Mayo and Colonel The Master of Sempill.

Central Library for Students.

Mr. J. E. Hodgson (Hon. Librarian).

Busk Studentship

The Trustees announce that there is a vacancy in the Busk Studentship in Aeronautics.

The Studentship is of the value of about £150, tenable for one year from October 1st; but a student may be re-appointed on the same terms for a second year. It is open to any man or woman, being a British subject and of British descent, who had not attained the age of 25 on October 1st, 1924.

Forms of application for the Studentship can be obtained from Professor B. M. Jones, Engineering Laboratory, Cambridge, and must be filled up and returned to him not later than May 12th.

W. LOCKWOOD MARSH.

THE ROYAL AERONAUTICAL SOCIETY

ANNUAL GENERAL MEETING

The Sixtieth Annual General Meeting of Members of the Society was held in the Library on Tuesday, March 31st, 1925.

In presenting the Council's Report and Accounts, the Chairman, Lieutenant-Colonel H. T. Tizard, said:—"I must ask your indulgence in inflicting on you rather a longer speech than is customary on these occasions. The Society has been passing through difficult times since the war, and these difficulties have recently culminated in the resignation of our Secretary, Lieutenant-Colonel Lockwood Marsh. This has come about in the following way. Our excess of expenditure over income in the last three years has been £279 in 1922, £316 in 1923, £359 in 1924, and in consequence our small invested funds, which were accumulated during and directly after the war, are practically exhausted. Towards the end of last year, the Finance Committee of the Council made a report drawing attention to what was, I fear, only too obvious, namely, the urgent necessity of either increasing income or decreasing expenditure. On the question of reduction of expenditure, a glance at the Society's accounts will show you that there are only two items of expenditure which might conceivably be reduced to such an extent as to make income cover expenditure, namely, the cost of administration and the net cost of the Journal.

The Council were emphatically of the opinion that the idea of reducing the cost of the Journal by limiting its size and circulation was not to be entertained. The utility, and the prestige, deservedly high, of the Society depends very largely on the high standard set by its Journal, and I feel sure that the Council will carry the whole of the Society with them in insisting that, if sacrifices have to be made in order to maintain, and indeed improve on, that standard, then those sacrifices must be made. On the question of reducing the cost of administration, the Secretary at once placed his resignation in the hands of the Council, in order to leave them quite free to take whatever action they thought proper. But the Council felt that the loss of a permanent Secretary was a serious matter, and that they could not accept this resignation without examining the possibilities of increasing the income of the Society. All the Societies of our standing and responsibilities find it necessary to have a permanent Secretary to represent their views and to look after their interests, and as showing how valuable the services of Colonel Lockwood Marsh have been outside his immediate sphere, I might remind you that he organised the whole of the Air Congress in 1923.

The Council considered the possibilities of increasing the subscriptions, but came to the conclusion that that could not be justified either on grounds of general policy or indeed of financial policy. They felt that, in the present state of the aeronautical industry, many possible members were already deterred from joining by the present amount of the subscription, and that any increase would probably be more than neutralised by resignations. They were able, however, through the efforts of the Secretary and Mr. Pritchard, the Editor, to effect some improvement in the net cost of the Journal by entering into a new advertisement contract, but this improvement, though welcome, does not by any means remove anxiety for the future. Finally, they addressed a letter to the Air Ministry, setting out the claims of the Society for special consideration, in the form of a grant-in-aid, from the Government. I am glad to say that this request

met with the greatest sympathy from the Air Ministry, who have done, and are doing, all they can to meet it; but unfortunately the decision rests in other hands, and has not been favourable. Colonel Marsh thereupon again tendered his resignation, and the Council has accepted it with great regret. They feel that facts must be faced, that it is essential for the Society to pay its way. The only possible way of doing this at present is by lowering the cost of administration, and much though we shall feel the loss of Lieutenant-Colonel Marsh, who has been with the Society for five years and whose services to the Society and to aeronautics in general are well known, we shall simply have to do the best we can till better times come, and try and induce some public-spirited member of the Society to act as part-time Secretary for a nominal honorarium. One of the first duties of the new Council will be to make such an appointment, and I hope they will find no great difficulty in doing so. We have been well served in this respect in the past, and I am glad to take this opportunity of recording our great appreciation of the services of our Honorary Editor, Mr. Pritchard. Much of the success of the Journal is due to Mr. Pritchard's self-sacrificing work, and indeed I do not know how we could get on without him. Mr. Pritchard has been looking after the Journal for five difficult years, and has consistently declined to accept any honorarium for his services. The Journal is well produced, well printed, and singularly free from printers' errors. One thing I feel certain that we can count on in the future as in the past—the loyalty and wholehearted co-operation of the secretarial staff, Miss St. Barbe and Miss Barwood, in assisting it over a difficult period and in doing all they can to make the routine duties of an honorary secretary as light as possible.

I said that the only possible way for the Society to pay its way is by decreasing the cost of administration. There is, however, another possibility, which I mention now, though I have no great hopes of its early fulfilment. What we want, in order to get into a really stable position, is an endowment fund of, say, not less than £10,000, the income from which would be applicable for the general purposes of the Society, and particularly for improving and extending the Journal. I mention this in the hopes that the appeal may reach the ears of those, limited unfortunately in numbers, who may be able and willing to help to extricate this old and famous Society from its financial difficulties, to set it firmly on its feet, and so to help on the development of aeronautics in this country in a way which will be none the less effective because it is not spectacular. I do hope that this appeal will fall not altogether on deaf ears. We have many influential and powerful friends outside, and perhaps when they realise our difficulties they will come to our help. This history of all other developments in applied science shows the importance of the existence of a flourishing independent society, which can encourage the free discussion of scientific and technical problems.

Now, before I sit down I want to refer to another matter of general importance. The Council viewed with some regret the formation of the Institution of Aeronautical Engineers in 1919, not that they wished to interfere in any way in the free development of any movement which would carry out duties and responsibilities which they were not themselves doing or capable of doing, but because they were unable to see how far the Institution did in fact do more than attempt to duplicate the work of the Society. Any such duplication is to be deprecated, since it dissipates effort and financial resources. Negotiations have been going on for some time now with a view to the amalgamation of the Institution with the Society, and though some difficulties remain, I am hopeful that a satisfactory solution will be found. If the Councils of the two Societies agree on a scheme, it will be necessary for the agreement to be ratified at a special general meeting of the Society."

In reply to a question, the Chairman said that he did not think the proposed amalgamation of the Institution of Aeronautical Engineers would benefit the

Society financially. He thought the Council would have to consider the possibility of reducing the subscriptions. The Council would certainly consider the possibility of holding joint meetings with other bodies on the lines of the recent joint meeting with the Institution of Automobile Engineers.

The Council's Report and Accounts were then formally adopted.

The following Members were declared duly elected to the Council for the two years ending March, 1927:—Major R. H. Mayo, O.B.E., F.R.Ae.S., Mr. T. O. M. Sopwith, C.B.E., A.F.R.Ae.S., Mr. C. W. Tinson, A.F.R.Ae.S., Mr. H. T. Vane and Sir Henry White-Smith, C.B.E.

Wing Commander T. R. Cave-Browne-Cave moved that "The Society place on permanent record its great indebtedness to the retiring Secretary, Lieutenant-Colonel W. Lockwood Marsh, for his services during the past five years." Particularly as regards its technical activities—which were essentially the purpose for which it existed—the position of the Society had very greatly improved during the Secretary's tenure of office. The organisation of the business of a society such as this was an extremely difficult matter and its satisfactory conduct during the exceptionally difficult years since he assumed office at the end of 1919 left the Society with a great debt to Lieutenant-Colonel Lockwood Marsh. It was the cause of great regret that it was impossible to continue to benefit from his assistance.

The motion was seconded by Sir Henry White-Smith, who said that he was sure they were all of one mind in desiring to place on permanent record the very great debt of gratitude they felt to Colonel Lockwood Marsh, and he would like to make particular reference to his work in making the Air Congress of 1923 the success it undoubtedly was.

The resolution was carried unanimously.

PROCEEDINGS

FIFTH MEETING, SECOND HALF, 60TH SESSION.

A meeting of the Royal Aeronautical Society was held in the Society's Library, at 7, Albemarle Street, London, on Thursday, March 19th, 1925, when a paper on "Practical Navigation of Aircraft" was read by Captain F. Tymms, M.C. Lieutenant-Colonel H. T. Tizard, A.F.C. (Chairman of the Society), presided.

PRACTICAL NAVIGATION OF AIRCRAFT

BY CAPTAIN F. TYMMS, M.C.

It is somewhat difficult to write a paper on the navigation of aircraft without devoting a considerable part of it to going over old ground. The general principles of aerial navigation are in no way new. It is only in the application of the principles that progress has been made, and much of this progress has already been described. This paper should therefore be regarded merely as a general survey of the methods available and the conditions in which they may be employed.

Navigation has been variously described as a science and as an art—the former because it is based on exact measurement and calculation, the latter because exact calculation does not always produce the desired result. Latterly, by reason of certain animated discussions which have taken place on the subjects "to navigate or not to navigate," "when to navigate and when not to navigate," I have come to doubt whether it is either a science or an art, whether in fact it is not merely a subject of controversy. By devoting some part of this paper to the controversial aspect of the subject, a not unimportant one, I hope to break some new ground which may be of interest.

Navigation resolves itself into two problems—the setting and keeping of a course, and the fixing of position. The number of ways of doing the first are few, but of the second there are many. Dead reckoning is the term applied to the process of keeping an account or reckoning of the course and distance run. This, combined with a modicum of map-reading or visual observation of the ground traversed, constitutes the simplest form of navigation, called air pilotage. All more advanced forms of navigation are merely highly refined methods of obtaining a fix. Thus radiogoniometric or D.F. navigation is a combination of dead reckoning (D.R.) with the fixing of position by wireless bearings. Similarly astronomical navigation consists of dead reckoning combined with position fixing by astronomical means.

When a pilot sets out to fly to Paris and follows the railway of his choice, he is setting a course. In his mind he keeps a rough dead reckoning. When he comes to the station he remembers having seen the day before yesterday he has made a fix. All the elements of navigation are there. The principles are the same when the operations are carried out with maps and instruments of precision.

It is necessary then to consider when the railway course shall give way to the compass course, and the memorised fix to the map fix, the wireless fix or the astronomical fix. If one shares the view which has recently been freely expressed that the pilot of the future will be a somewhat *passé* replica of the engine driver of to-day, then there is no need to consider the question any further.

I do not share this view—a view which is the negation of the newly-won freedom of the air. I am impelled by my own experience and that of others to the conclusion that the air must follow the sea and the aeroplane the ship rather than the iron-bound train, and that these questions are of vital importance in the future of aviation.

One must first consider the methods and instruments available and assess their value.

The first essential in navigation, though one might almost say it comprises the whole problem, is to maintain direction. Two things come naturally first in the study of this part of the problem—maps and compasses.

Maps

Without a map the desired direction cannot even be ascertained. We are justified therefore in placing this requirement first.

The navigator, apart from requiring his map to show him the topographical features of the earth, requires three things of it. The map must show distances correctly, it must show bearings correctly, and it should be possible to join adjacent sheets accurately. The first two requirements are capable of two interpretations. Both the bearings and distances may be along the great circle, or they may be along the rhumb line.

Great circle bearings are usually called azimuths. The navigator is concerned with both of these, but rather more with the rhumb line.

To assess the value of a map for navigation, therefore, involves some study of projections.

In the early stages of one's experience with maps, a map is a map—even if in some cases it is torn from the pages of a Bradshaw. There comes a time, however, when the truth begins to dawn that a map may be one of many things, and doubts arise which only become deeper with one's first contact with books on the subject. Now the number of projections and modifications thereof is almost endless. They all have different properties and have been produced to serve every conceivable purpose—even to ensure a passage to Heaven—as in the case of the Retro-azimuthal projection designed to show Mahomedans the true direction of the Qibla in Mecca.

Without a very long study of the subject we can only get a clear idea by restricting our inquiries to those maps and charts which are readily available for the use of navigators. If there are projections, other than those we use, which have more valuable properties, it is rather the map-maker's province to produce them than the immediate concern of the navigator. The navigator should, however, realise the limitations of the map he is using. We shall see that it is only in certain cases that special precautions have to be taken, and that with the majority of topographical maps, if their limitations are realised, all the ordinary operations can be performed without fear of serious error.

In navigation we are mainly concerned with relatively small areas—the area which will cover the distance to be flown on one course. If we put this at 300 miles, we are putting it at a figure which is rarely likely to be exceeded except by airships. If accurate bearings and distances are required for distances greater than this, they are better obtained by calculation. The navigation map, therefore, should give bearings and distances with a fair degree of accuracy up to 300 miles. Most of the projections adopted for existing survey maps will do this with a greater or less degree of accuracy.

The projection *par excellence* for navigation is Mercator's. This projection has been at various times attacked, mainly on the ground that it gives an erroneous idea of the shape and relative size of the land and water masses of the earth. This, though an adequate condemnation of its use as a school map,

does not touch the problem of navigation. It has been said that since Mercator's projection was presented to navigators as a solution of their problems by Gerard Kauffman in 1556, many other better projections have been produced, and that these should therefore now be used for navigation. It has been said that since the great circle track is the shortest route between two points, maps for navigation should be drawn on a projection which shows the great circle as a straight line. Such projections exist, but they do not compete with Mercator.

The crucial point in the argument involves the means for maintaining the craft's head in the required direction, viz., the compass. By reference to the compass the machine's head is kept at a constant angle to the meridian, which is invariably the reference line. Mercator's projection is so constructed that the rhumb line or loxodrome, which is the path of an aircraft steering a constant true course in a calm, appears as a straight line—in other words, the meridians are drawn parallel, so that all straight lines cut every meridian at the same angle. This involves a distortion of scale, the scale of the map increasing from the equator to infinity at the poles. Mercator's projection is therefore not suitable for use in the vicinity of the poles, but this is not of practical importance at present. Although the scale varies with changes of latitude, yet distances may be measured with accuracy by reference to the scale of latitude appropriate to the positions of the points in question. This varying scale is a trap for the unwary, but with practice it is not a practical difficulty.

Finally, any number of sheets of Mercator's projection compiled on the same equivalent scale, *i.e.*, with the degrees of longitude of equal length, may be joined together to form a composite map of the world, excluding of course the areas near the poles. On such a composite map a straight line may be drawn between any two points, the rhumb line course measured by reference to any meridian, and with suitable precautions the distance between the two points measured.

These are qualities which are combined by no other projection.

Practically all marine charts are produced on Mercator's projection. The course generally followed has been to suit the area and scale of the sheet to the shape and size of the water areas to be charted. The land masses, with the exception of their coastal areas, are of no interest to the marine navigator. There has grown, therefore, a collection of marine charts of varying size, shape and scale which it is not possible to join together to form a composite chart.

Mercator's projection was rightly chosen for the general sheets of the International Aeronautical Maps which are now being produced on the general lines laid down in the International Convention. As befitting the new science of aviation, these maps are being produced on a regular plan. The aerial navigator is concerned with land and sea—even more with land than sea. It was therefore possible to plan a series of maps on a uniform equivalent scale which may be joined together to form a composite map.

Each general sheet of the International Aeronautical Map is constructed on a scale of "1° of longitude=3 cms.," and covers 12° of latitude with an overlap of 1° north and south and 18° of longitude with an overlap of 2° east and west. Specimens of these maps are shown. The details of the map will be reverted to later.

The scale is equivalent approximately to 1/3,250,000 at the equator and 1/2,350,000 in the latitude of London. The scale selected is one which cannot be advocated as suitable for navigation. It is a smaller scale than it would be possible to use for any but long flights over desert or sea where landmarks are rare, and where the "landfall" is prominent. It has a certain value, however, as a strategic map and is useful for the general planning of routes.

The other projection which has a certain special use in navigation is the Gnomonic, the projection of the earth's surface from the centre on a plane

tangential at any point on the surface. The peculiar feature of this projection is that any straight line drawn on it is an arc of a great circle. From our point of view it has no other good qualities. Its scale increases in every direction from the point of projection to infinity at 90° from that point. It cannot therefore be used for measuring distances without calculation. Bearings are only correctly measured at the centre of projection, but these bearings are of course great circle bearings or azimuths.

Since all forms of wave transmissions, neglecting deflections, are received from a direction along the great circle, or in other words the wave front is normal, at the point of reception, to the great circle joining the point of transmission and the point of reception, this property would be of value in dealing with long distance radiogoniometric bearings. Assuming a gnomonic chart constructed with its centre of projection at Croydon, a D.F. bearing received at Croydon could be laid down as a straight line on the chart and this line would pass through the position of the transmitting station. As a matter of fact, if a special chart were being constructed, the two-point azimuthal projection could be used, on which it would be possible to lay down great circle bearings from two points, which could be Croydon and Pulham, or any other two D.F. stations. In practice, however, within the normal range of working of direction-finding wireless stations on existing air routes, it is not worth while to construct such a chart, and the bearings can be laid down with negligible errors on other existing maps.

In practice, therefore, the utility of the gnomonic projection is limited to the laying down of a great circle track, for the purpose of studying its position or to assist in plotting it on another chart of more general utility, and this at present is of more moment to the marine than to the aerial navigator.

It will be convenient to refer to other projections in connection with the actual examples which have to be used by the aerial navigator. The aerial navigator, not yet having sufficient maps drawn specially for his use, must draw from the existing surveys of suitable scale. For practical purposes the limiting scales of maps suitable for navigation are 1/200,000 and 1/1,000,000. Larger scale maps are unnecessary and necessitate the carrying of too many sheets. Smaller scale maps show insufficient detail except for a flight along a coast or river such as the Nile, where even a map on a scale of 1/2,000,000 gives practically all the information required.

The ideal scale of a map for navigation purposes appears to be in the neighbourhood of 1/500,000 (approximately eight miles to the inch). Unfortunately few maps on this scale exist. There is a ten-mile to the inch map of Great Britain which in its present form is not suited for navigation. Meridians are not shown, and if they were, they would be excessively curved. There is a good 1/500,000 series of France and a very good one of Germany. There is also one of Italy which is rather lacking in detail. These series can be used for navigation, subject to the precautions described below for the international 1/1,000,000 series. A specimen of an aeronautical map of the London-Paris route on this scale (1/500,000) is shown.

One of the most useful of the existing maps, because it covers the largest area on a uniform scale and projection, is the international 1/1,000,000 map, which was first projected at the International Geographical Congress in Berne in 1891. The proposals did not take definite shape until 1909, since when a number of sheets have been produced on a more or less uniform plan. Sheets cover 4° of latitude and 6° of longitude, *i.e.*, approximately 250 mile squares in this latitude. Sheets covering practically the whole of Europe, with the exception of Spain, and also Asia Minor, Iraq and Persia and parts of India, can now be obtained, though not all have been produced in the full colour scheme, showing contour layers. With the inclusion of some sheets of the Indian 1/1,000,000

series, it is possible to obtain maps on this scale for a flight from London to Rangoon.

This map is drawn on a modified polyconic projection—a projection which makes it possible to join any sheet to the four adjoining sheets, and any number of sheets from east to west, but which does not permit the accurate joining up of two such strips. The scale error is not cumulative since each sheet is constructed independently on its central meridian, and the scale adjusted to its limiting parallels and meridians. Distances may therefore be measured with all the accuracy required for navigation.

The meridians are straight lines converging towards the pole, the parallels of latitude are arcs of eccentric circles, and a straight line drawn on the map approximates more nearly to a great circle than to a rhumb line. In measuring bearings on this map a close approximation to the rhumb line bearing is obtained by laying down a straight line between the two points and measuring its bearing with reference to the meridian midway between the two points. The error in adopting this procedure within the limits of 300 miles laid down is not detectable by the ordinary method of measuring angles with a protractor.

It should be borne in mind that this straight line is not the rhumb line and therefore will not be followed by the aircraft. Its divergence from the rhumb line increases in sheets nearer the pole and reaches a maximum for each sheet on east-west courses. Since the meridian is both a great circle and a rhumb line there is no divergence on a north-south course.

The maximum divergence of the rhumb line from the straight line occurs midway between the two points. Taking, for example, two points 300 miles apart in latitude 50°, the greatest distance of the straight line from the rhumb line is about six miles. The rhumb line in this case is, of course, the parallel of latitude and the bearing 90° or 270°. If the course were measured with reference to the initial meridian, it would be 87° or 273°, and if the aircraft were flown on this course it would miss its objective by about fifteen miles. The difference in bearing is roughly equal to the conversion angle, *i.e.*, the angle between the great circle and the rhumb line.

It may be taken, therefore, that this map may be used for navigation purposes with suitable precautions. It may be objected that the scale is too small for the use of pilots, but there are some pilots who already use it regularly.

Coming to maps on a larger scale, the number of projections used multiplies, and it will be impossible to examine them all in detail.

To the navigator in England, the map of most importance is the Ordnance Survey map of England and Wales, on a scale of four miles to the inch (1/253,440). This map is constructed on Cassini's projection (plotting by rectangular co-ordinates)—a projection which is only suitable for very small areas or, more particularly, for areas of small extent in longitude.

This projection is, in effect, a projection on a cylinder tangential to the earth's surface along the central meridian. It is easy to show that the central meridian will be a straight line, that all great circles cutting the central meridian at right angles will be straight lines, and in consequence that the parallels of latitude, except the equator, are not, also that small circles parallel to the central meridian will be straight lines (such are the sides of the sheets of the ¼ inch O.S. map), and in consequence that the meridians, except the central one, are not straight, also that the scale north and south becomes increasingly incorrect as one gets further away from the central meridian. Straight lines therefore are not generally rhumb lines. Those running east and west from the central meridian are great circles; the central meridian, itself a straight line, is a great circle or a rhumb line; other straight lines running N. and S. are small circles; and straight lines running in other directions are neither rhumb lines, great circles nor small circles.

This map could not be extended with any accuracy beyond the limits of Great Britain, and we are only concerned with the errors which occur within its limits. The maximum error of bearing will occur in a line measured east or west, having a slightly greater value in the north of England than in the south, and in a line measured north or south near the extreme east and west coasts. The error in the east-west bearing is approximately equal to the conversion angle which, from a point in west Wales to (say) Yarmouth, about 250 miles, is approximately $2\frac{1}{2}^{\circ}$. As in the case of the international 1/1,000,000 series, a closer approximation to the rhumb line bearing is obtained with reference to the meridian midway between the two points. As regards error in scale, this is less than would be accounted for by expension and contraction of the paper. On a meridian 2° east or west of the central meridian, say the meridian of Greenwich, the error in scale north or south is only about .06%. Since all the sheets for England and Wales are plotted with reference to one central meridian, it follows that all the sheets can be accurately joined together. The sheets of England and Wales, however, cannot be joined to the similar series of Ireland because these latter are plotted on a different meridian. One of the important points to note about this projection, one which is common to most topographical maps, is that the meridians are not parallel to the sides of the map, and that bearings cannot therefore be measured with reference to the edge of the map. Ignorance of this point has led to many errors.

In a general paper of this kind it is not possible to extend this examination of maps to the other projections used for topographical maps, but it will generally be found that similar precautions are necessary unless the distances are small. In Bonne's projection for example, which is very widely used on the continent, notably in the French 1/200,000 map, it follows from the fact that the parallels of latitude are arcs of circles, and the meridians, complex curves, that rhumb line bearings cannot be accurately measured, and even that the scale is not strictly correct in all directions.

The conclusion, therefore, is that maps should be used with discrimination, that courses and distances of the order commonly required by aircraft can be measured from any topographical map within the limits of accuracy permitted by distortion of the paper, that a straight line on the map rarely represents the accurate course of an aircraft from point to point, and that for long courses special precautions must be taken, while when specially long courses or great accuracy is required, results should be obtained by calculation.

The formulæ used are :—

Rhumb Line.

(1) Tan course = D. Long. / d.m.p.
where D. Long. is the difference of longitude in minutes, d.m.p. is the difference of the meridional parts for the latitudes of the points.

(2) Distance = D. Lat. × sec. course.

Great Circle.

The great circle bearing (or azimuth) may be approximately obtained by adding the conversion angle for westerly courses or subtracting it for easterly courses, the conversion angle being obtained from the formula :—

(3) Conversion angle = D. Long. / 2 × sin mid. Lat.

If the azimuth is accurately required, it should be obtained by solution of the spherical triangle, using the formulæ :—

(4) *Distance*, hav a = hav (b $\pm$ c) + sin b sin c hav A
where a = distance between the two points,
b = colatitude of one point,
c = colatitude of the other point,
A = D. long.

(5) *Azimuth*, hav B = cosec c cosec a $\sqrt{\text{hav (b - a + c) hav (b + a - c)}}$
or hav C = cosec b cosec a $\sqrt{\text{hav (c - a + b) hav (c + a - b)}}$
where B and C are the azimuths at the two points respectively.

Alternatively :—

(6) Tan $(B + C)/2 = \cot \frac{1}{2}A$. sec $\frac{1}{2}$ (b + c). cos $\frac{1}{2}$ (b ~ c)

(7) Tan $\frac{1}{2}$ (B ~ C) = cot $\frac{1}{2}$A. cosec $\frac{1}{2}$ (b + c). sin $\frac{1}{2}$ (b ~ c)

It should be noted that the azimuth is only required for work in connection with radiogoniometry. In what is called " great circle sailing," *i.e.*, navigating along the great circle (which could obviously only be profitable in long journeys oversea), the azimuth is not the first course to steer. Consideration of Fig. 1 will show that this is so.

Fig I

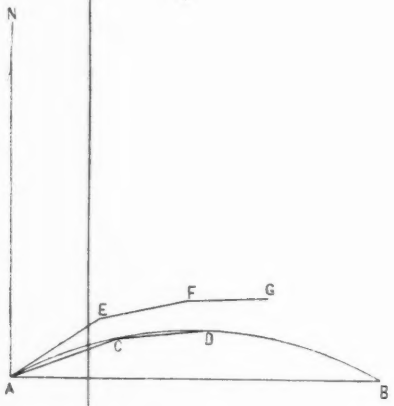


FIG. 1.

The line A C D B represents the great circle between A and B, as it would appear plotted on a Mercator's chart, A B being the rhumb line and A N the meridian through A. One can only approximate to the track A C D B by steering a series of courses such as A C, C D. The azimuth of B from A is the angle N A E, A E being a tangent to the curve at A. By steering a course N A E therefore the craft would continually recede from the great circle, somewhat along the line A E F G, and however frequently the course were altered the craft would inevitably reach a point on the polar side of B. By steering a course such as N A C however, the track of the craft continually returns to the great circle and by more frequent alterations of course, any degree of approximation to the great circle track may be obtained. The azimuth or, as it is wrongly called, " the great circle first course," is of purely academic interest in the steering of the craft—a further argument against the substitution of an azimuthal projection for Mercator's.

So far we have discussed maps with reference to their mathematical properties. It is necessary also to examine their pictorial qualities, by which I mean the extent to which they do or do not adequately represent the surface features of the earth.

There is a fairly general view that a map for aerial navigation should be a picture of the earth as seen from an aeroplane. This is an eminently sound principle, subject to the limitation of all principles, that it should not be ridden to

death. If carried too far, this particular principle would result in a map which would be very difficult to read because of the crowded nature of the information and the diverse appearance of similar things.

A map should primarily be clear to read. It is far better for a pilot to see a black outline on his map in the position of Croydon aerodrome, a sign which catches his eye, than to have a picture of the aerodrome as it looks, which he probably would not see. It is impossible to reproduce pictures a quarter of a million times reduced. Again, some roads are black, others white, and some even are red. A map cannot show them in their proper colours. The confusion would be too great and the expense prohibitive. What the map can do is, with a proper selection of tone values, to give to roads generally their proper importance relative to other landmarks. The same applies to towns, which are generally red in the Midlands and grey in Scotland. A town is an important landmark which must stand out conspicuously on the map. If towns were shown in their natural colours, they could only be made conspicuous by altering the colours of the surrounding country. Again, taking into account the height at which commercial aviation now takes place, and probably any height at which aviation will be a commercial proposition in the future, the contours of the land are of vital importance, and should be shown clearly on the map. The most popular form of contoured map amongst pilots is a layered map, one which distinguishes different altitudes by a range of colours, so that high land stands out conspicuously. The adoption of such a system still further limits the possibility of making a map a picture of the country.

One is forced to the conclusion that a map for aerial navigation must follow in general the principles on which all maps are produced—that surface features must be shown by conventional signs. Familiarity with the conventional signs is the key to the reading of the map. A good map reader will see a picture of the country in a good map; a poor map reader will see little in the best map.

It will be of interest to record briefly how the problem has been dealt with in the new international aeronautical maps of which five general sheets have now been published by Great Britain.

In the general sheets, buff has been adopted as the basic colour for sterile country and pale green for fertile country; contours are shown on the layer system by neutral shading with the addition of spot heights; roads are shown in a uniform shade of light brown to be less conspicuous than the railways, which are shown in maroon; water is, as always, blue, woods dark green, towns and industrial features red; black is reserved exclusively for aeronautical information, which includes aerodromes, wireless stations, lighthouses, prohibited areas, danger areas and names.

In the local sheets, of which so far only two provisional sheets have been drawn and none published, the same general system has been followed. These two sheets, corresponding to sheets 11 and 12 of the $\frac{1}{4}$ inch Ordnance Survey of England (old series), are merely reproduced from the Ordnance Survey maps, with suitable amendments of the conventional signs; they are therefore on Cassini's projection.

In this case, the base of the map is white; contours are shown by hill shading in neutral tint with the addition of spot heights; aeronautical information is given in greater detail and includes as many prominent landmarks as can conveniently be shown. The method of showing these landmarks provides an interesting example of what is possible and what is not possible in the direction of making a pictorial map. A well-known figure of a giant cut in the chalk hillside near Lewes is shown pictorially in black. An even more prominent landmark formed by the chalk scar of the new road cutting in the Downs at Wrotham has to be described in words as "Chalk Cutting." On a clear day this can be seen from the south coast near Hastings, but any attempt to show it pictorially on the map would effectually prevent its being found.

Turning to other maps which have not been produced for aerial navigation, but have at present to be used, the ¼ inch Ordnance Survey map provides an interesting comparison with the provisional local aeronautical map. One point in particular may be cited; the classification of roads on the Ordnance Survey map gives them a fictitious value from the aviator's point of view, which is avoided by the uniform colouring adopted on the aeronautical map. The ¼ inch O.S. map is very popular with pilots in spite of the fact that it is purely conventional in representation; this can be ascribed to their familiarity with it.

The international 1/1,000,000 map is not strictly a topographical map and it is therefore to some extent lacking in detail. On some of the sheets, contours are well shown by colour layers, with the addition of spot heights. Towns, rivers, railways and main roads are shown, but an important omission from the aerial point of view is woods. The features shown are sufficient in normal country.

The many remaining series of topographical maps of Europe and other countries are some of them good, and some of them distinctly bad, and the chief lesson to be learnt is that the bad ones show how very necessary is the provision of proper aeronautical maps.

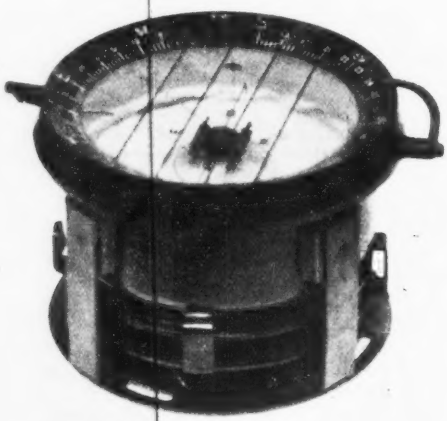


FIG. 2.
P.2 *Compass.*

Compasses

The development of the magnetic compass has probably reached a higher standard in England than in any other country. We are still only concerned with the magnetic compass for practical navigation since other compasses have not yet reached a stage of development at which they can be put into practical use.

The magnetic compass is a much abused instrument, but, with proper treatment, it is capable of rendering very faithful service.

Since the introduction of the first aperiodic compass, magnetic systems of the aperiodic type have been designed for most of the older types of compass. There are at present, therefore, quite a number of different types in use, but four models, all with modified magnetic systems approaching aperiodicity, have been standardised to meet all probable future requirements.

P.1 Compass.—This compass is still in the development stage and is designed to meet the views of those pilots who prefer steering by a vertical card compass. One is inclined to the view that the dislike of the grid system of steering, as used

in the P.2 model, is only a passing phase, and that there will be no necessity for the continued use of a vertical card compass, except to achieve a different end, *i.e.*, to put the compass further away from the engine, in a way which is referred to later.

P.2 Compass.—This is practically the original model of the aperiodic compass, provided with an improved spring mounting and one or two other modifications. It has no card but is fitted with a graduated verge ring to which are attached parallel wires. The verge ring being set to the desired course, the craft is steered so as to keep the compass needle parallel to the grid wires.

FIG. 3.
O.1 *Compass.*

O.1 Compass (Centesimal scale).—This compass was produced for the use of an observer or navigator, to facilitate quick reading of the actual course being steered, such as is required when taking radiogoniometric bearings in the machine. Neither the P.1 nor the P.2 compass is well suited to this operation. No provision is made for taking bearings with this compass. A fixed scale of 100° is provided, the damping wires being set at 0°, 100°, 200° and 300°. The course can be read by taking the hundreds figure from the damping wire and the tens and units from the fixed scale.

O.2 Compass.—Like the O.1, this is an observer's compass. A very light horizontal scale is mounted at the extremities of the damping wires, but sufficiently far from the inner surface of the bowl to reduce to a minimum the effect of swirl set up in the liquid by friction. A prismatic sight is mounted on a rotating ring on top of the bowl, and a quick release mounting is provided so that the compass can be readily moved from one position to another in the aircraft, so enabling bearings to be taken in any direction.

Practically all the troubles of the compass can be eliminated by fixing it in a suitable position in the machine, at least three feet from the engine and as far as possible from other large steel masses. Unfortunately, this cannot always be done without impairing the pilot's view of it, an equally fatal fault. The difficulty hardly arises on a twin-engined machine, and varies very considerably on different single-engined types. Cases have occurred where the deviation of the compass on the instrument board of a single-engined machine could only be

reduced to normal proportions by the use of such a large number of corrector magnets as to practically neutralise the earth's directive force. In this condition the compass was useless, as the least vibration set it spinning. The only remedy was to put the compass by the side of the pilot, a position which is far from ideal. The proper place for the compass is directly in front of the pilot, and many pilots prefer it also to be at eye level—this latter incidentally requiring a vertical card compass. Designers of aircraft are now paying more attention to compass requirements in their new machines, but at the same time designers of compasses are realising that it is not quite reasonable to demand that aircraft shall be built round their compasses, and the position is being reviewed.

FIG. 4.
O.2 Compass.

The Mirror Reading Compass.—If the compass can be placed behind the pilot's seat, it is usually sufficiently far from the engine and other metal parts of the aircraft to be free from serious deviation. In one Condor-engined machine a difference of 60° in the deviation of the compass was observed as between the dashboard position and the position behind the pilot's seat. A 256 pattern compass has therefore been fitted with a domed glass window to provide the necessary magnification and a mirror mounted on the instrument board, in which the pilot reads the compass, which is situated just behind and to one side of his head. The mirror may be rotated so as to reflect the image in any desired direction; the reading of the compass is not affected by parallax as long as the mirror is so arranged as to reflect to the pilot's eye a ray which reaches it parallel to the fore and aft line. This system is at present in an experimental stage, but it is hoped that it will go far to reduce the difficulty of fitting compasses to certain types of machines. This system has the advantage of ensuring that the view of the compass is level with the pilot's eyes.

Compass Errors

Apart from bad fitting, the compass is subject to the disturbing element of the vertical component of the earth's magnetic force, which operates whenever the card departs from its normal horizontal position, either in a banked turn or through oscillation of the machine. Both causes of disturbance have their maximum effect when the machine's head is north or south magnetic, because in this position, when the card is tilted about an axis parallel to the fore and aft line of the machine, it is free to turn under the downward pull on the north seeking end of the needle.

The error occurring when the card is tilted is called "northerly turning error," though the term is sometimes restricted to those cases where the error is of such dimensions as to cause the compass to register a turn in the wrong direction.

Major Wimperis has shown* that in the new types of compass having a magnetic system approaching aperiodicity, both the banking and oscillation errors have been very greatly reduced, and that these compasses will not register a turn in the wrong direction.

The position remains, however, that the magnetic compass will not register correctly while the machine is turning, and consequently cannot be depended on in cloud or fog without the aid of a turn indicator to ensure that the machine is flying straight and level.

The steering of a compass course for navigation purposes is often confused with the holding of a constant compass course. The latter is required in photographic air survey operations and is a matter of considerable difficulty, which has been the subject of long experiment, notably under the direction of Professor Melvill Jones of Cambridge.† What is required in ordinary navigation, however, is merely the steering of a correct mean course. The machine's head may swing through 3° or 4° or even more in bad weather, but if the pilot balances out the swings to either side of the correct course, the effect on the track is negligible. Cases can be cited where in flights of 100 or 200 miles, the wind conditions being uniform, the machine has not deviated by more than a quarter of a mile from the rhumb line. Such results are the rule rather than the exception with pilots who are accustomed to steering compass courses.

It is important to realise that good results cannot be expected from the compass without proper maintenance, any more than from the aircraft itself. The magnetic condition of the metal of an aircraft is not constant and it is therefore necessary to adjust the compass periodically. This is less necessary when a good position has been found for the compass where the deviation is small, but generally speaking the compass should be "swung" every month, and after every change of engine. The following table of deviations of an aperiodic compass fitted just below the instrument board of a D.H.34 illustrates the necessity.

	D.H.34.			H.P.W.8.b.
Aircraft Head Magnetic.	Deviations on 18th April.	Deviations on 12th May.	Deviations without correcting magnets, 12th May.	Deviations.
N.	+ 2°	—	+ 3°	—
N.E.	+ 5°	— 6°	+ 9°	+ 1°
E.	+ 1°	+ 1°	+ 8°	—
S.E.	—	+ 2°	+ 4°	— 1°
S.	—	— 5°	— 6°	—
S.W.	—	— 5°	— 12°	—
W.	— 2°	—	— 7°	—
N.W.	— 4°	+ 3°	— 6°	+ 1°

* *R.Ae.S. Journal*, "Some Recent Developments in Aircraft Instruments," January, 1924.
† *Nature*, May 26th, 1923.

The engine was changed between April 18th and May 12th.

The fourth column shows the amount of deviation which may have to be corrected in a compass placed in front of the pilot on a single-engined machine.

The last column of the table shows the deviations of a similar type of compass after correction on a twin-engine machine, the compass being fitted in a similar position.

The deviations of the compass should be analysed, whenever it is swung, by the approximate formula :—

$$\delta = A + B \sin \zeta + C \cos \zeta + D \sin 2\zeta + E \cos 2\zeta,$$

δ being the deviation on a compass course ζ, and A, B, C, D, E being angles called the approximate coefficients of deviation.

A is constant on any course.

B is mainly due to permanent magnetism in a fore and aft direction, and has a maximum value on east and west. C is mainly due to permanent magnetism in an athwartship direction, and has a maximum value on north and south. D and E are entirely due to induced magnetism and their effect is a maximum on the quadrantal points. It is not customary to correct for D and E in aircraft as the quantity of soft iron is small.

The practice of analysing the deviations assists in eliminating compass trouble. Errors in the lubber line are particularly common and are shown by coefficient A. "Rule of thumb" methods of correcting compasses should be eliminated. The most obvious errors have been known to find their way on to deviation cards—errors which would immediately have been detected by analysis.

The swinging of land machines is either carried out on a marked-out base or with the aid of a landing compass. The swinging of seaplanes is most conveniently carried out in the same way, but large machines are awkward to handle and it is sometimes necessary to swing them on the water.

There are several ways of doing this. All require a considerable number of personnel. The method requiring least personnel consists in taxying on a series of different courses across a line of transit, and at the moment of crossing observing the compass course and the bearing of the points in transit with reference to the fore and aft line of the machine. The bearing may be observed with a bearing plate. From the deviations observed, the deviations on all other points may be calculated by means of the above formula or read off on a curve constructed from the observed values.

The disadvantage of this method is obviously the amount of engine-running required in the taxying.

Another method requiring more personnel is carried out at moorings. The machine is slowly pivoted round the buoy by towing. A bearing compass is mounted on shore, and at the moment the machine's head crosses the cardinal and quadrantal points, reciprocal bearings are taken from ship to shore and shore to ship, and the machine's head by compass observed. This provides the necessary data. Calm weather and slack water are required.

In view of the talk of polar flights and trans-polar air routes, it is of interest to consider the efficacy of the magnetic compass in the Arctic regions. At the north magnetic pole the earth's total force is vertical and the compass card would therefore be without control. Based on this fact certain too sweeping statements have been made to the effect that the magnetic compass is of no value in other parts of the Arctic, *e.g.*, in Spitsbergen, which is in 80°N. latitude. An aperiodic compass with an intensified magnetic system was used by the Oxford University Expedition on an Avro seaplane in the north of Spitsbergen in the summer of 1924, and while conditions did not necessitate reliance being placed on the compass, certain experiments were carried out.

It was found that the time of swing of the needle back to rest after deflection was approximately double that observed in England. Since the earth's horizontal force H in England is .18, and H was observed independently by the expedition in the north of Spitsbergen to be about .09, this result is to be expected. Having less directive force, the compass was naturally more sluggish, but this was not so serious as to render it useless.

The magnetic dip in Spitsbergen is 81°.30′ as compared with 67° in the south of England, but the effect of this was hardly noticeable, any tendency of the magnetic system to tilt being counteracted by the high point of suspension.

For many polar flights it seems probable that the magnetic compass, if provided with an intensified magnetic system, as far as its correct functioning is concerned, could be used, certainly as well as in many parts of the north and north-west of Canada, which are nearer the north magnetic pole than is the geographical pole itself, and where flying operations are at present carried out. The chief difficulty, however, lies in our lack of knowledge of the essential magnetic element—declination. Observations in Spitsbergen showed a difference of magnetic declination of 10° between two places 160 miles apart. In Europe this same difference could only be obtained in a flight of nearly 900 miles. This rapid change, which is to all intents and purposes uncharted, would render the magnetic compass almost useless over the uncharted polar seas.

Observations seem to point to a greater intensity of magnetic storms in the polar regions than in Europe. On one day the magnetic declination was observed to vary as much as 2½°. This, however, would not be of serious consequence in navigation.

Sun Azimuth Compass

To obviate the difficulty of using the magnetic compass, Captain Ammundsen proposed to use a sun azimuth compass constructed for him by the firm of Zeiss. Based on the clockwork control of a mirror which can be set for any desired course and adjusted for any desired latitude, to keep pace with the changing azimuth of the sun, the instrument is designed to throw an image of the sun on to a screen, and the machine is steered so as to keep the image on a central mark. Obviously, such an instrument would have limited value on the London-Paris route. In the Arctic, however, there is considerably more sun than is commonly supposed, and there are many days in the summer when it would be possible to use it.

The Turn Indicator

The turn indicator is essentially a pilot's instrument, and it is not proposed to discuss it in detail. It has been shown that it is a necessary adjunct to the compass in certain conditions, *i.e.*, when flying in cloud or fog and sometimes when night flying. It is one of the "immediate action" instruments in an aircraft and with the compass should have priority of place in front of the pilot.

All but one of the existing forms of turn indicator are gyroscopically controlled. The static head turn indicator suffers from the disadvantage of having a considerable lag in its indications. Of the others, one is inclined to favour the instrument which indicates by means of lights rather than by a pointer on a dial. The latter requires watching the whole time, while the lights call attention to themselves.

Whatever the form of indicator used, it has been clearly proved that it is an instrument, the successful use of which requires training and practice. Almost more than any other, it is an instrument which the pilot is liable to distrust until he has had personal experience of its successful operation, and this he can only get by using it first in good conditions. Pilots who have had practice in its use are usually firm believers in its value.

Measurement of Drift

From the steering of a course, one proceeds to the correction of the course for drift.

There are two methods of doing this. The first is to observe the apparent direction of motion of objects on the ground beneath the machine and measure the angle between this line and the fore and aft axis of the machine; the second, less used, but more reliable method, is to observe the bearing, with reference to the fore and aft axis of the machine, of some object which has been passed over in flight, or alternatively, if the passing of the object has not been observed, of the point astern which maintains a constant bearing.

The first method is the one for which practically all instruments have been designed, but it has the disadvantage that rolling as well as yawing motions of the aircraft are converted into an apparent drift, necessitating the estimation of a mean direction of drift. This becomes difficult on a rough day. In the second method the rolling motion of the aircraft has no effect, and in addition it is much easier to estimate the mean bearing of an object than its mean path.

The instrument in common use for the measurement of drift is still the 6in. Mark I Drift Bearing Plate, which merely consists of an open drift wire rotating inside a calibrated circle. This instrument has to be fitted on the side of the machine or in the floor—a position which is not available in civil machines. Fitting the instrument on the side of the machine necessitates the navigator leaning out in the slipstream in order to take an observation, an operation which should not be required in commercial aircraft. To obviate this, a periscopic form of drift indicator is now being developed.

This instrument projects through the side of the fuselage and must be fitted so as to provide a clear view vertically downwards from the object glass. The image of the ground is reflected by prisms into a horizontal eye-piece in front of the navigator's seat. A rotatable drift line is included in the optical system, and this is operated at the eye-piece, where a calibrated disc indicates the angular setting to port or starboard. A prism at the object end of the periscope is rotable so as to alter the field of view forward and aft. The drift wire is calibrated fore and aft as a ground speed meter.

Preliminary reports on the use of this instrument show very satisfactory results up to 16,000 feet. It is possible that this form of drift indicator will be suitable for the use of pilots and so meet a requirement which has hitherto received little consideration.

It may be noted that with the methods and instruments described up to the present it is possible to navigate with absolute accuracy when the ground is visible, whether the country is surveyed or not, and moreover these methods, except for the use of wireless telephony, are the only ones open to the pilot flying the machine. It is not absolutely necessary to know how far the aircraft has progressed, but it is absolutely necessary to know that it is progressing in the right direction.

The application of the drift indicator to this method is simple and is merely a refinement of the method used by many pilots called "the two-point method."

Having ascertained the desired track, the machine is steered on this course and the drift observed. The course is then altered into wind by the amount of the drift angle. If the drift angle is small, the course will now be practically correct, and the track of the machine will be the desired track. If the drift angle is large or the wind strong, the second drift angle will differ from the first so that a further correction of course is necessary, the new course being the desired track $\pm$ second drift angle.

It may be that a third change of course is necessary, but this will rarely be the case. It is even possible, if the wind velocity is about half the air speed, that

the first change of course will reverse the direction of the drift, and in these conditions a small error in the course may cause a much greater error in the track. Steering in these conditions is difficult, but fortunately they are rare. Rules can be formulated to facilitate the finding of the correct course to steer in these conditions, but in practice it is probably as well to find it by trial and error.

When this method is used and allowance made for any subsequent changes in the wind, and consequently in the drift, the pilot may rest assured that he must

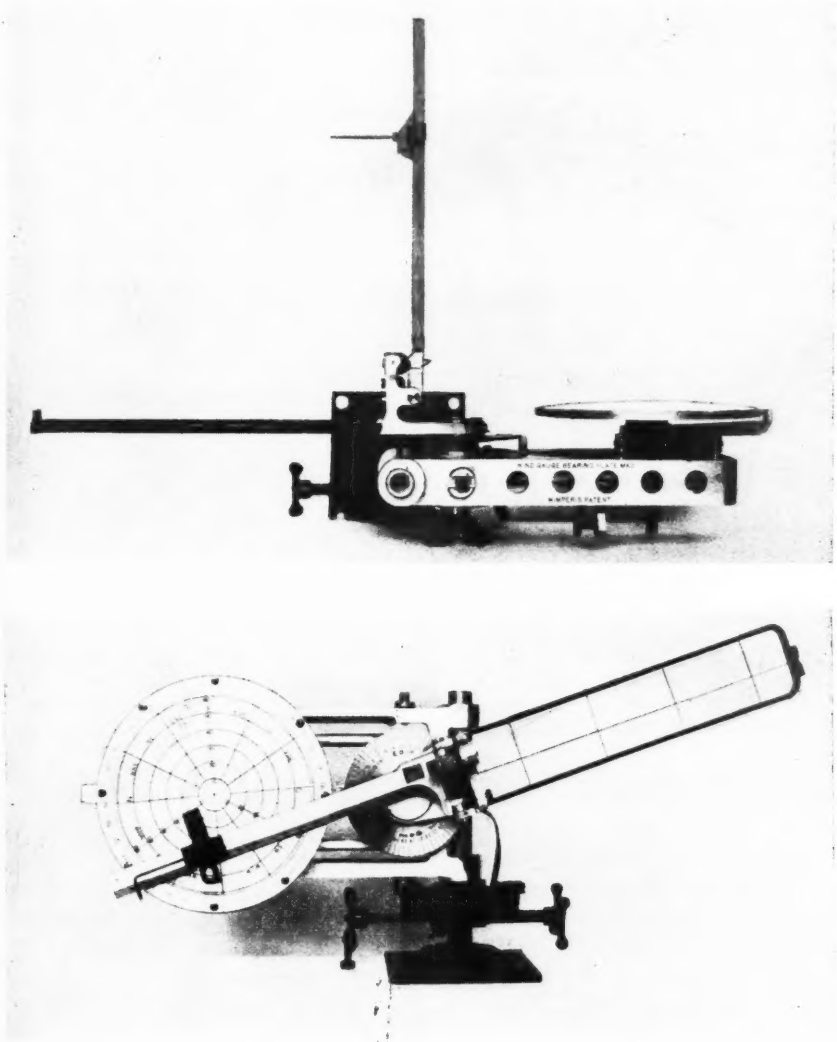


FIG. 5.
Wind Gauge Bearing Plate.

get to his destination. Numberless examples of long flights over sea using no other method might be cited, but two will suffice. It is understood that the American round the world pilots flew from Attu Island in the Aleutians to Paramushir in the Kuriles, a distance of 740 miles over open sea on this method alone, and that there was no appreciable error in their course. An even more famous example was afforded by the late Captain Sacadura Cabral in his flight of 1,000 miles from the Cape Verde Islands to the St. Paul Rocks. Captain Cabral's navigator, Admiral Gago Coutinho, observed the drift by means of drift angles marked on the tail plane.

Wind Gauge Bearing Plate

The principle and construction of the Wind Gauge Bearing Plate has previously been described.* Figure 5 shows the latest model which has the advantage of weighing only 5 lbs. against the 8 lbs. of the first model, while the drift bar is extended beyond the plotting plate in order to give a clear view of the ground. In the first model it was necessary to observe the drift through the glass plotting plate, an arrangement which gave a smaller field of view and partially obscured the view by reflection.

FIG. 6a.

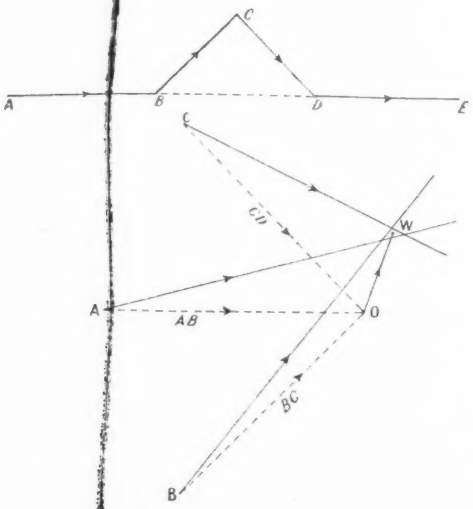


FIG. 6b.

This instrument is invaluable for flights over sea or uncharted country, where a direct measurement of ground speed is difficult. By a suitable arrangement of the courses flown, the machine deviates very little from the desired track while the observations are being taken. In Figure 6 (a) A B is the first course, B C the second course at an angle of 45° to the first and C D the third at an angle of 90° to the second.

Observations of drift are taken on each of these courses and the original course then resumed along D E, the whole operation taking about four minutes.

Figure 6 (b) shows how the drift lines or tracks would appear plotted on the

* *R.A.S. Journal*, "Air Navigation," Major H. E. Wimperis, August, 1919.

bearing plate, the dotted lines representing the courses steered, which are not drawn on the instrument. A "cocked hat" is formed at W, the centre of which is the wind point. O W represents the wind in strength and direction and the ground speed along the track corresponding to the course A B or D E is represented by A W.

Measurement of Ground Speed

All bearing plates are provided with ground speed scales consisting of sights which can be adjusted to subtend varying angles according to the height of the machine, so that the angle covers a definite distance on the ground, usually half a mile. Two systems are possible, based on (1) an angle fore or aft from the vertical, (2) an angle bisected by the vertical, as shown in Fig. 10 (a) and (b) respectively.

The former is less efficient because, as will be seen from the figure, a slight angular tilt alters the length of the base line (Fig. 7 (a)), while in the second case (Fig. 7 (b)), the effect of tilt on the length of the base line is small. The latter system will be incorporated in the periscopic drift sight.

The disadvantage of all ground speed scales is that the base line is too small for accuracy, and that it is difficult to avoid an error in estimation of height. It

FIG. 7a. FIG. 7b.

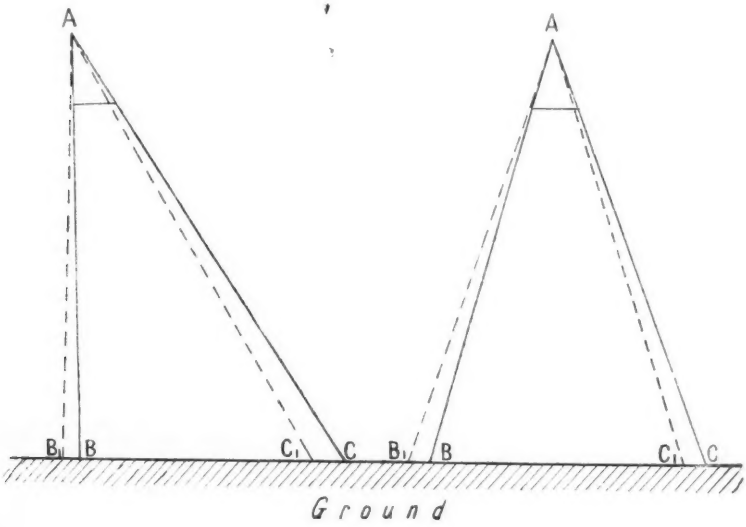


FIG. 7.

is therefore better to measure ground speed by timing a run between two points recognisable on the map, or, if these are not available, by the use of the Wind Gauge Bearing Plate.

Solving the Vector Triangle

From the maintenance of direction, one proceeds to the estimation of position, called dead reckoning. For this, a mechanical means of solving the vector triangle is required. This calls for no particular comment, except that the existing instru-

ment used in this country is an unsatisfactory mechanical proposition, and there is room for the development of a new instrument, which will not only solve the single vector triangle, but also the problem which is so elegantly dealt with by the Wind Gauge Bearing Plate.

Captain Cabral's navigator, Admiral Coutinho, used an instrument of his own design for the solution of this problem, but this instrument, which he called a Course Corrector, was designed for the solution of a particular case, which it does by a very pretty geometrical construction.

In order to ascertain quickly the amount of drift on the course which would give the desired track, the machine was steered first in the direction of the desired track, then at 45° to it. The instrument gave the wind point from the intersection of the two tracks as in the Wind Gauge Bearing Plate, but it also gave the loci of all the wind points which produced the same ground speed along the desired track and of all the wind points which produced the same angle of drift with reference to the desired track. From the intersection of these loci, the course could then be set immediately. All the results were given with reference to the air speed of the machine and the direction of the desired track, so that there still remained certain calculations to make.*

This method is worthy of comment because Coutinho's navigation was probably the finest piece of aerial navigation which has yet been done. At the same time, it is not considered necessary to devote a great deal of space and time to a detailed description of the instrument, because of its limited application.

Position Fixing

From dead reckoning the next step is to the fixing of position, and practically all the remaining processes in navigation come under this heading.

There is a number of methods, well known to marine navigators, of fixing the position of a craft with reference to visible distant landmarks. All of these may at some time or other be useful to the aerial navigator, but as compared with their use at sea, their value in the air is very limited. The observer of a fleet spotting machine may frequently have to use them, but it is only on rare occasions that one can visualise their being used by the navigator of a commercial aircraft.

Radiogoniometry

The growing use of direction finding wireless telegraphy as an aid to navigation, and its greater convenience for aircraft work as compared with the older astronomical methods, puts this first among the external aids to position fixing to be considered. Not least among its advantages is the fact that its use is not limited to certain conditions of weather, though its accuracy varies in certain conditions.

There are three distinct methods of use of radiogoniometry, (a) direction finding by one or more ground stations, (b) direction finding in the aircraft by fixed wing coils, (c) direction finding in the aircraft by a radiogoniometer.

(*a*) *D.F. by ground stations.*—This is the only method which has so far been used by commercial aircraft and the one which has been familiarised by its use on the London—Continental routes, worked by the D.F. stations at Croydon and Pullum.

Experience has shown that the average error in the bearings recorded is 1.54° and that errors of 5° to 10° may occur. Bearings are always reported as 1st or 2nd class bearings, so that pilots may judge what reliance may be placed on them. The percentage of bearings reported as 1st class is between 20 and 30. About 90 per cent. of these are accurate within the limits of the available methods of checking.

* "Aerial Navigation," Coutinho and Cabral, published in *Anais do Club Militar Naval*, Lisbon, 1922.

The value which these two D.F. stations have proved to civil aviation may be judged from the extent to which they are called on by pilots flying on the continental routes. The number of positions given to aircraft during the six months ending December 31st, 1924, was 140 and the number of bearings 36.

D.F. bearings are subject to special errors when the path of the wave passes along a coast line and at night when the wave traverses any considerable extent of land. In these circumstances, the bearings have to be treated with caution.

It is interesting to note the effect of the average error in a D.F. fix when two such fixes are used for the calculation of the wind by the ordinary processes of D.R. navigation. Assuming each bearing to have an error of $1\frac{1}{2}°$, at a distance of about 60 miles from each D.F. station, the error in the fix might be 2 miles. The error in the second fix might be a similar amount in the opposite direction. The vector error in the run, from which ground speed is calculated, would therefore be 4 miles. This might be in any direction relative to the track, either along it, in which case the error would be solely in the ground speed, or at right angles to it, in which case the error would be confined to the direction of the track.

In either case, the error represents in amount and direction the vector error in the calculated wind. Since, in practice, on a short route one cannot generally afford to take a longer time interval than $\frac{1}{4}$ hour, this error in the fixes results in a vector error of 12 miles an hour in the calculated wind.

This points to the necessity of using the longest time interval possible, having regard to the length of the course being flown. This is a principle which is common to all navigation processes. It has been referred to in connection with measurement of ground speed by visual methods, and it becomes even more important in astronomical navigation.

(*b*) *Wing Coils.*—This may be looked on as a method of steering the craft, but since to steer the craft entirely by the aid of wing coils to a beacon station would require continuous transmission, the method is not a substitute for the compass. The method is strictly one of position fixing, though it is usual only to obtain one position line.

Recent experiments have shown that it is possible for an aircraft fitted with wing coils to be guided to within a few hundred yards of the transmitting station. It will be realised, however, that the path of the aircraft in approaching the station, if there is a side wind, will be a curved one, and, theoretically, the final course on passing over the station, whatever the direction of approach, is up wind. In order to reach its destination along a straight course, it is necessary to steer the machine into wind away from the bearing of the transmitting station by an amount equal to the angle of drift, which can be ascertained by observing that the craft's head by compass remains constant on successive observations, or, in other words, that it is necessary to turn the machine's head through the same angle for each observation.

When flying away from a beacon station, the drift is again the angle through which it is necessary to turn the machine in order to obtain a tail bearing of the station.

The disadvantage of the wing coil method for general work is the necessity of turning the machine in order to obtain a bearing. In order to get a fix, it is necessary to do this twice, directing the machine in succession on two different stations.

The advantages of the method more than outweigh the disadvantages, bearing in mind that its chief use will be on organised routes for homing on a beacon station situated on a terminal aerodrome. It has the advantage over the ground D.F. station method—an advantage which will probably, in the near future, be decisive—that it enables the same beacon station to be used at the same time by any number of aircraft.

XUM

(c) *D.F. in the machine.*—The system which has been used up to the present involves the use of rotating coil aerials. These coils take up a considerable amount of space, which precludes their use in commercial aircraft. There is still, however, a method by which D.F. bearings may be taken in the aircraft with apparatus of reasonable dimensions. This system is the Bellini Tosi system, and it is at present, as far as its fitting in aircraft is concerned, purely in an experimental stage.

The apparatus consists of two fixed loop aerials of large dimensions, one in the fore and aft line of the machine, fixed round the fuselage, and the other at right angles to it running along the upper and lower planes and down two opposite pairs of struts. A small searcher coil or radiogoniometer is provided and the bearing with reference to the fore and aft axis of the machine, read off on a dial. A compass is fitted in a good position to be read by the operator at the moment of taking a bearing. The O.1 compass (centesimal scale) is designed for this work though the O.2 may be used if it is desired at the same time to carry a bearing compass.

The system is obviously only suitable for use on a machine carrying a navigator, and will have its peculiar value on routes which are not highly organised. Its great merit is the freedom it confers on the navigator to make use of any wireless station either on or near the route, which may be transmitting, and to do this without altering course. To those who think in terms of navigation, it has the additional merit of keeping the responsibility for the navigation of the craft on the crew and not on the ground personnel.

Direction finding by this method also has the advantage of permitting the simultaneous use by any number of aircraft, of one ground station. On the other hand, the quadrantal error of the machine has to be ascertained and allowed for. This error is due to reradiation of energy from the metal parts of the aircraft, and may be plotted against the course as an approximation to a sine curve—hence its name. It is probable that this error will be entirely eliminated in the design of the apparatus.

Before any wireless bearing can be laid down on the map, a further correction has to be made for conversion angle, *i.e.*, the angle between the rhumb line and the great circle. This can be ascertained by the formula already given, or with sufficient accuracy by an approximation, varying with the mid-latitude of the station and the aircraft. In the latitude of London it is approximately equal to 1° for every $2\frac{1}{2}$° difference of longitude. Its limiting values are 0° at the equator and an angle equal to half the difference of longitude at the Pole. It is additive when the aircraft is west of the transmitting station and vice versa.

A gnomonic chart on which the bearings could be laid down directly as great circles offers no advantages in this case because the bearing at the station differs from that at the aircraft by approximately twice the conversion angle, which would therefore still have to be calculated. A chart may be constructed showing lines of equal bearing from a certain transmitting station. Each line is the locus of all points from which the bearing of that station is constant. Since only a very limited number of transmitting stations could be so dealt with, the use of such a chart would destroy the main value of the system. The bearings should therefore be dealt with by calculating the conversion angle and laying them down as rhumb lines on the navigation chart.

Astronomical Navigation

The value of astronomical observations in aerial navigation is a debatable point, but the value to an aerial navigator of a knowledge of the problems involved is undeniable, and we are not justified, therefore, in dismissing the subject from consideration, whatever the conclusion as to its value in practice.

Any problem in astronomical navigation resolves itself into a measurement of the altitude or zenith distance of a celestial body, an exact record of the time of the observation, and subsequently a solution of the spherical triangle of which the elevated pole is one apex, the geographical position of the celestial body another, and the observer's position the third.

In modern navigation, until the problem of taking observations in the air was tackled, the observation of the altitude could only be performed with the marine pattern sextant, by which the altitude of the body above the visible horizon was measured, an allowance made for dip, refraction, semi-diameter and parallax, and so the true altitude obtained. In passing, it may be said that parallax is a quantity of too small an order to be important in aerial observations, and that semi-diameter and dip are eliminated by the use of a bubble sextant.

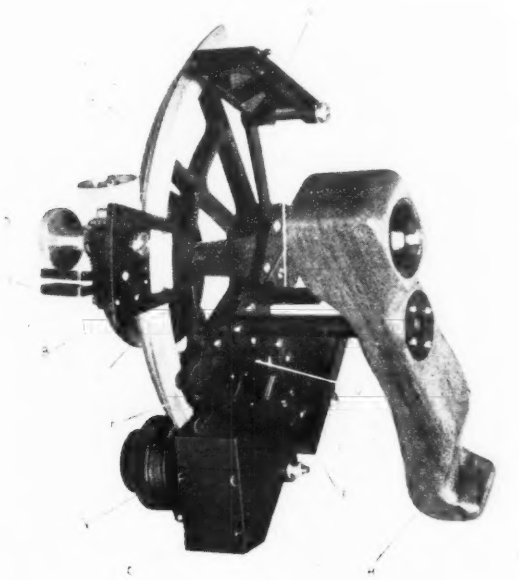


FIG. 8.
R.A.E. Sextant, New Pattern.

The difficulty in the use in the air of any sextant depending on a natural horizon is, first, that the horizon is much less frequently visible from an altitude than it is from sea level, and secondly, that there is always a doubt as to the observer's height above the visible horizon and consequently as to the amount of the allowance for dip.

To meet this difficulty the R.A.E. sextant, among others, was produced, with an artificial horizon or, more correctly, an indication of the vertical, in the form of a bubble level. This sextant and the principle on which it is constructed has already been described.*

Fig. 8 shows a later model built on the lines of the marine pattern sextant with a bubble system enclosed in a single unit attached. This bubble system is

* *R.Ae.S. Journal*, "Some Recent Developments in Aircraft Instruments," January, 1924.

collimated in the same way as in the original pattern in such a way that for any setting of the sextant, in small angular movements, the image of the celestial body and the bubble move together. The bubble unit is so constructed that it can be thrown out of the line of sight, leaving the sextant free to be used in the normal way with a natural horizon. One of the advantages of this model for aircraft work is its reduced weight—$3\frac{1}{2}$ lbs. against the 5 lbs. of the older model.

When flying above cloud, it is possible with this sextant to observe the dip of the horizon with reference to the rational horizon indicated by the bubble. The mean of a long series of observations is taken at leisure, and with certain conditions of stable cloud this observation of the dip may be used in conjunction with a subsequent measurement of altitude above the cloud horizon. The advantage gained is that the actual observation for position may be reduced to a single sight, whereas when altitude is measured with reference to the bubble, at least six observations must be taken in order to reduce, by taking the mean, the errors due to acceleration acting on the bubble. There is also a considerable saving of time in eliminating from the actual calculation of position the process of meaning the times of observation, and the altitudes observed.

As the normal method of using the sextant is by a direct use of the bubble, it is important to know what errors may be expected and consequently what use may be made of the observations taken.

It has been found that the errors due to acceleration acting on the bubble show no consistency in direction; the larger the number of observations of which the mean is taken, therefore, the nearer is the approximation to the truth. The number of individual readings is limited in practice, and it has been customary to take the mean of six, which can be observed comfortably in about four minutes. The probable error of the mean is then approximately two-fifths of the probable error of a single observation. The errors being due mainly to reference to a false vertical, due to acceleration, it follows that they will be of greater magnitude in bad weather.

Observations taken on aeroplanes in "good," "moderate" and "bad" weather show probable errors in the means of six observations of 5, 7 and 9 minutes of arc.* On airships, in weather conditions which for this purpose may be called "good," the probable error of the mean of six observations was found to lie between $1\frac{1}{4}$ and $2\frac{1}{2}$ minutes of arc, the smaller error occurring in observations taken in the direction of the fore and aft line and the larger in observations taken athwartships.

The probable error of individual observations taken with a natural horizon sextant from an aeroplane has been found to be 9′. Since it is customary to take only single observations to a visible horizon (the error in the observation being perceptible at the time), and since the weather conditions above the clouds are "good," this error is comparable with the first of the errors given for the bubble sextant, viz., 5′. It has to be remembered that, while with a bubble sextant the errors are "random" errors, which are reduced by taking the mean of a number, the error of the natural horizon observation is due to an inaccurate estimation of the height of the observer above the horizon and is therefore a fixed but unknown quantity. The dip of the horizon in minutes of arc is usually taken to be equal to $.98\sqrt{H}$ where H is the height in feet, from which it is clear that errors in H of the magnitude likely to occur when the horizon is distant—in other words, when H is large—will have considerable effect.

The record of the time of the observation requires fewer precautions in the air than at sea, on account of the lower degree of accuracy attainable in the observation and required in the result. An error of four seconds in time introduces a maximum error of one minute of arc into the result—an error which is not

* A.R.C. Report. R. & M. 816.

important in comparison with the errors occurring in the sextant observations. The necessary accuracy in time can, on most occasions, be obtained from a good watch which is compared with a time signal before the flight, thus to a certain extent avoiding the troublesome precautions necessary with a chronometer.

The common method of making use of an astronomical observation is the Marc St. Hilaire method of drawing a position line at right angles to the azimuth of the celestial body. To obtain the data for this position line, the zenith distance and azimuth are calculated from the D.R. position, the azimuth laid down on the chart through the D.R. position, and a line drawn at right angles to this line through a point at a distance from the D.R. position equal to the "intercept," or difference between the calculated and observed zenith distances.

In so far as astronomical sights will be used in the air, this method looks like becoming the universal one. It has the great advantage, particularly at night, of providing a position line which may be used in conjunction with any other position line, *e.g.*, a wireless bearing, to obtain a fix. The greater speed of aircraft limits the use of other methods which are commonly used at sea. For example, the meridian altitude or noon sight, which is an article of faith at sea, is simple because it requires no solution of a spherical triangle, but in the air one cannot afford to wait till noon. The same applies to a less extent to the ex-meridian altitude, because by day it can only be obtained near noon, and at night it only gives an east-west position line, when the observation of some other star might give a position line in a more useful direction. The second argument applies also to the "latitude by Polaris" method, for which special reduction tables are given in the Nautical Almanac each year.

Now that the general solution of the spherical triangle has been simplified by the use of the Bygrave Slide Rule (which has been described by Major Wimperis*) there is not the same need for these special solutions of particular cases, and we can assume that the normal method of using astronomical observations is the general one of laying down a position line at right angles to the azimuth.

The solution of the triangle by the aid of the Bygrave Slide Rule takes from three to four minutes in the air, but this does not include the extraction of the necessary elements from the Nautical Almanac and the calculation of the hour angle. The time required for this process can be reduced while still retaining all the accuracy required by extracting the values for the period covered by the flight before leaving the ground. For example, the maximum rate of change in the equation of time is about 1.3 seconds in an hour. By taking the same value over a period of three hours, therefore, the maximum error introduced into the result would be one minute of arc. A little more trouble has to be taken with declination where the greatest rate of charge is approximately one minute of arc in one hour. A curve of declinations for the period of the flight to assist in rapid interpolation is useful.

Everything possible should be done on the ground before the flight, so as to eliminate as far as possible reference to books of tables, which, in addition to adding to weight, are confusing to use in the condition of decreased mental efficiency from which most people suffer in the air. Even when all this is done, allowing for the stowing away of the sextant and watch, change of position for the taking of the sights, and all the little things which devour time, it is unlikely that a position line could be put on the chart in under fifteen minutes.

The value of the position line in these conditions must be critically examined. It is true that the most probable position of the aircraft is on the position line, but where the possible errors are of the order of thirty or forty miles, the navigator requires to know something more than this. Assuming a flight above

* *R.Ae.S. Journal*, "Some Recent Developments in Aircraft Instruments," January, 1924.

the clouds, so that the weather conditions are "good," the probable error of the position line has been stated to be five miles. If, therefore, two lines are drawn parallel to and five miles distant from the position line AA as A_1A_1 in Fig. 9, then the odds are even that the position of the aircraft is somewhere in the band between the two lines. In order to increase the odds to ten to one, so as to give a reasonable sporting chance that the craft's position is within the band, the lines must be drawn at twelve miles from AA as at A_2A_2.

If another position line BB be laid down at an angle of not less than 60° with AA, then the lines B_2B_2 enclose the corresponding ten to one band, and the odds are ten to one that the error in the fix is not more than double the error in the position line, *i.e.*, twenty-four miles. This error may be wholly in direction, *i.e.*, at right angles to the track, or wholly in distance, *i.e.*, along the direction of the track.

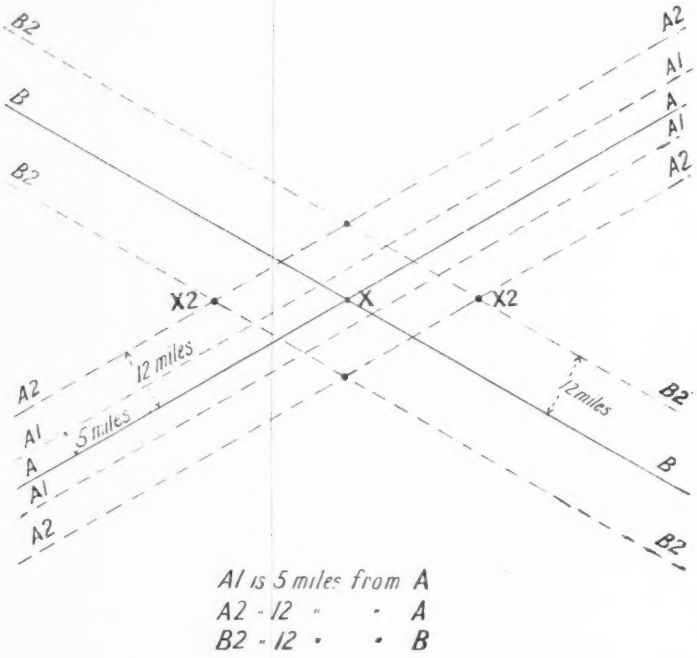


FIG. 9.

Considering this in relation to a flight of 300 miles, at a speed of 100 miles an hour, the first case is equivalent to an error of $4\frac{1}{2}°$ in the track and the second to an error of eight miles an hour (or eight per cent.) in the ground speed.

The following average laws governing the vector change of wind with time and place have been empirically established by the Meteorological Office :—

(*a*) At heights between 1,000 and 3,000 feet, vector change in three hours is 4.1 m.p.h. 12°.

(*b*) At the same heights, vector change per 100 miles is 4 m.p.h. 15°.

It has been found that these laws cannot be held to apply to distances greater than about 100 miles. In a flight of 300 miles, therefore, a change of wind of

any magnitude might be experienced, and assuming conditions where no meteorological information is available, and where the navigator is unable to obtain wireless bearings or drift readings (*e.g.*, over clouds), then the undetected errors in D.R. position might considerably exceed the above-mentioned sextant errors.

It seems to be a safe conclusion, therefore, that there are conditions when an astronomical sight, even of the accuracy at present obtainable, may be of value. These conditions do not occur at all in flights of less than about 300 miles, and then only in flights over sea or uncharted country. The value of the observations increases as the length of the flight is increased.

The worst conditions have been assumed in the above case. If only one astronomical position line is used in conjunction with a track line observed by drift measurements over the sea or in conjunction with a D.F. bearing, the error due to the sextant observation is only half those given above. The errors in the observed drift increase with the distance flown and the errors of a D.F. bearing with the distance from the station, so that again the relative value of the astronomical observation, which is independent of these factors, improves with the length of the flight.

In the case of airships, whose speed we may put at fifty miles an hour, the position is much better. In the first place the ten to one position line errors are only six miles, and the ten to one fix errors only twelve miles. In a 300-mile flight, therefore, the error in the calculated track might be $2\frac{1}{4}^{\circ}$ and the calculated ground speed error two per cent. Considering the different conditions of operation of an airship as compared with an aeroplane, it is not surprising therefore that astronomical navigation is looked on as a normal method of fixing position by airship officers.

Fog

The problem introduced by fog is much less one of navigation than of engines and landing. This is a platitude, but one may perhaps be excused for stating it in order that the misconception which exists as to the attitude towards this question of those concerned with navigation may be cleared away. No one advocates flying in fog at present. Pilots must first have full confidence in their engines, and the landing problem must be overcome. No one, in fact, advocates flying in fog at all. The aim must be to make flying more comfortable, not less so, and to this end to fly above fog or cloud rather than beneath it. The turn indicator has its place in passing through the cloud.

Though not strictly a matter of navigation, it is perhaps as well to refer to two of the most promising methods of assisting aircraft to land in fog.

Leader Cable

By passing an alternating current through a cable laid just under the surface of the ground, an oscillating electro-magnetic field is created round the cable. An aircraft entering this field is enabled to detect the fact by the aid of two search coils, the planes of which are set at such an angle that an equal E.M.F. is induced in each coil when the lines of force are horizontal—in other words, when the aircraft is immediately over the cable. The E.M.F. induced in the coils is measured and recorded so as to indicate the height and the side to which the aircraft should be steered.

Model experiments have given very satisfactory results, and the height of the instrument above the cable was accurately indicated.

The manner in which it is proposed that this should be applied for the assistance of aircraft landing requires considerable spaces clear of obstructions

round the aerodrome, but this is a condition which will be common to any method of landing in fog. The cable will be laid in the form of a large oval round the aerodrome, the ends being large enough to require only a moderate rate of turn. One of the straight sections of cable will lead directly over the aerodrome. Distinctive signals will be received as various parts of the cable are passed over and particularly on the straight section to indicate when the aerodrome boundary is passed, so that the pilot will know when he is over the landing ground.

The installation of this system will undoubtedly be expensive, and it is doubtful whether, even if it proves successful, it could be installed at many aerodromes.

Sound Location

Efforts have been made at Croydon aerodrome to lead aircraft to the aerodrome by the aid of sound. A trumpet sound locator was mounted on a rotatable mounting on top of the control tower, immediately over the position of Croydon aerodrome on a map in the room below. The listener operated in this room, and the direction of the trumpet axes was indicated by a pointer over the map. The principle of these trumpet locators is similar to that by which, with the unaided ear, we obtain a sense of the direction from which a sound comes—generally referred to as the binaural faculty.* The trumpets, in fact, merely magnify the sound and lead it to the ear of the listener through ordinary stethoscope tubes. The listener having obtained the direction, the pilot was then told by wireless telephony in what sector he was on the map, to which he had a corresponding key.

This method was not satisfactory. In the first place its range (five to ten miles) was insufficient. Then a certain amount of time was bound to elapse before the pilot could be told where he was, and a further difficulty was created by the fact that the pilot had frequently wound in his aerial by the time he got within five miles of the aerodrome. Finally the trumpets collected all the extraneous sounds from the aerodrome (most of which were concentrated round the control tower) and so drowned the sound of the approaching aircraft.

It need hardly be said that any system which is going to be of assistance to aircraft landing in fog must give an immediate indication to the pilot. No delay for transmission of information is permissible. The leader cable complies with this requirement, and acoustic experiments with a view to overcoming the above difficulties are proceeding.

Night Flying

In view of the conflicting views which have been expressed on the question of what is and what is not necessary for successful night flying, it may be as well to set down what navigation can contribute to the problem.

On all except the darkest nights, enough detail of the ground can be seen to enable a drift observation to be taken, though possibly not sufficient to identify the position on the map, or even in many cases the nature of the objects seen. When weather conditions allow the ground to be kept in view, therefore, the destination can be reached by observation of drift.

As an auxiliary to this method, a certain number of lighthouses, whether aerial lights or marine lights, is necessary for the checking of position. Fig. 10 shows the system of aerial lights at present installed on the London-Paris route, together with a few of the more useful marine lights.

This map shows that at no time is an aircraft flying between London and Paris outside the range of visibility of some one of these lights.

There is reason to believe that the wing coil method of direction-finding will prove to be free of the night errors which affect direction-finding by ground

* *R.Ae.S. Journal*, "Sound Reception," August, 1924.

stations. This, therefore, may be used with advantage. Astronomical navigation, as has been shown, does not come into the problem on the routes which have first to be considered for night flying.

The special difficulty of the problem occurs when clouds are low, because clouds cannot be seen by night as they can by day. This necessitates a fuller system of meteorological reports along the route, even than that now supplied by day, including probably special cloud height reports from all the high ground

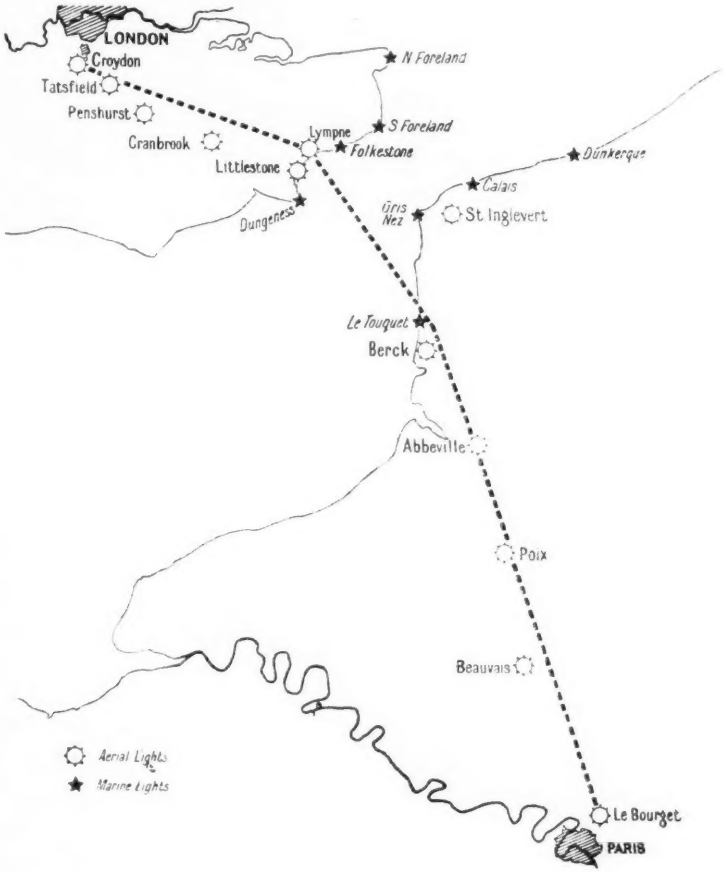


FIG. 10.
Aerial Lights.

along the route. The method which, by the supreme skill of the pilot, succeeds by day, of following valleys to avoid cloud, is too dangerous to attempt by night when neither cloud nor ground can be seen. The popular view at the moment is that the difficulty will be overcome by establishing lights every few miles, so that a pilot may follow the line of lights through valleys and thus avoid the cloud-capped hills. My personal view is that this will break down at very nearly the same point as will the compass course corrected by drift readings—that is,

when the clouds become so low that it is not possible to fly over the tops of the hills with a reasonable margin of safety.

This system has been adopted in the trans-continental air mail route in the United States between Chicago and Cheyenne, a distance of 885 miles. At each of five main aerodromes along this route there is a 450,000,000 candle-power revolving electric arc, with a visibility of 150 miles; at each emergency landing ground, on an average twenty-five miles apart, there is a 5,000,000 candle-power electric light, with a visibility of forty miles, mounted on a 50ft. tower, and in addition, at intervals of three miles along the route, there are 5,000 candle-power acetylene gas beacons, each having a range of seven miles. Operations under these conditions have been very successful.

The vital difference in the application of such a system in western Europe is the entirely different character of the weather and the much more enclosed nature of the country. Based on its success in America, an over-sanguine assumption has been made that not only will this system prove successful here, but that it is the only one which will. It is no injustice to the American air mail service to point out that no alternative system has been tried. The practice of navigation, and even the compass, is very much neglected in America, as one may gather from the fact that the section lines in the west are considered more valuable aids to navigation than the compass and that the more irregular topographical features of the east are considered to introduce a special difficulty.

The installation of this system is necessarily expensive and definitely limits the routes which can be flown, and it is questionable whether post-war European countries can afford to incur the expense, at least until the system has been proved to be the only possible one.

The arguments appear to me to be, first, that when the clouds are high enough to fly over the tops of the hills a chain of lights is unnecessary; and second, that when the clouds are so low as to necessitate flying through valleys, even the chain of lights may be lost sight of, or the conditions may so deteriorate as to make it impossible to continue, and then the parlous state of the aircraft following them is one in which no transport company should invite passengers to participate.

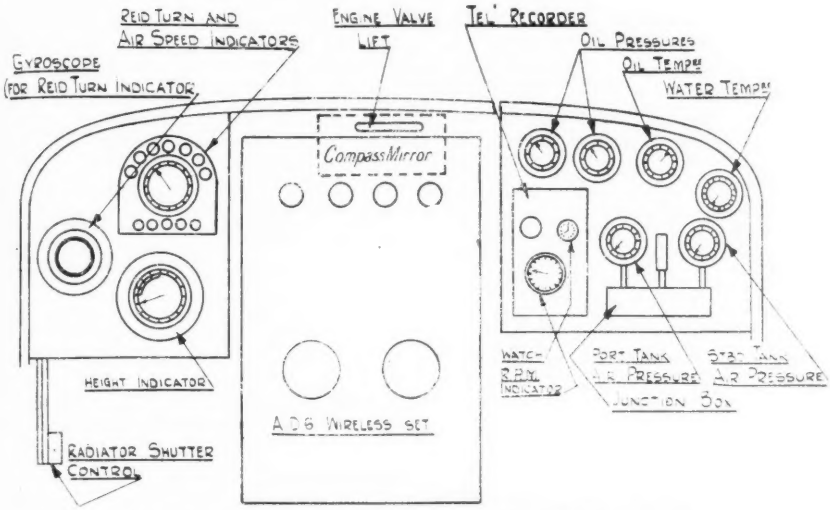
The only real alternatives when the clouds are low seem to be to fly above them or not to fly at all. The problems to be solved before flying above the clouds are identical with those discussed in connection with fog.

Accommodation for Navigator on Civil Aircraft

The provision of accommodation for a navigator on civil aircraft may appear to many to be a luxury unjustified by the present economic condition of air transport. It is noteworthy, however, that although not compelled by regulations to do so, certain companies have found it beneficial to employ navigators to fly on their ordinary services.

It is clear that for some time the only accommodation which can be made available for the navigator is the second seat in the pilot's cockpit. Certain essential conditions must be fulfilled in order that he may operate with success. By the courtesy of Imperial Airways Ltd., I am enabled to exhibit two drawings illustrating what is considered to be the ideal arrangement of the pilot's cockpit.

Fig. 11 shows how the instruments should be arranged on the dashboard. Immediately in front of the pilot are placed the instruments which demand immediate action on his part, viz., the air speed indicator and turn indicator. With them is placed the altimeter, which is next in importance. In the middle, under the coaming is the W/T set, in such a position that either the pilot or navigator can reach it to make adjustments. On the starboard side are grouped



VIEW OF DASHBOARD FROM PILOT'S SEAT.

FIG. 11.

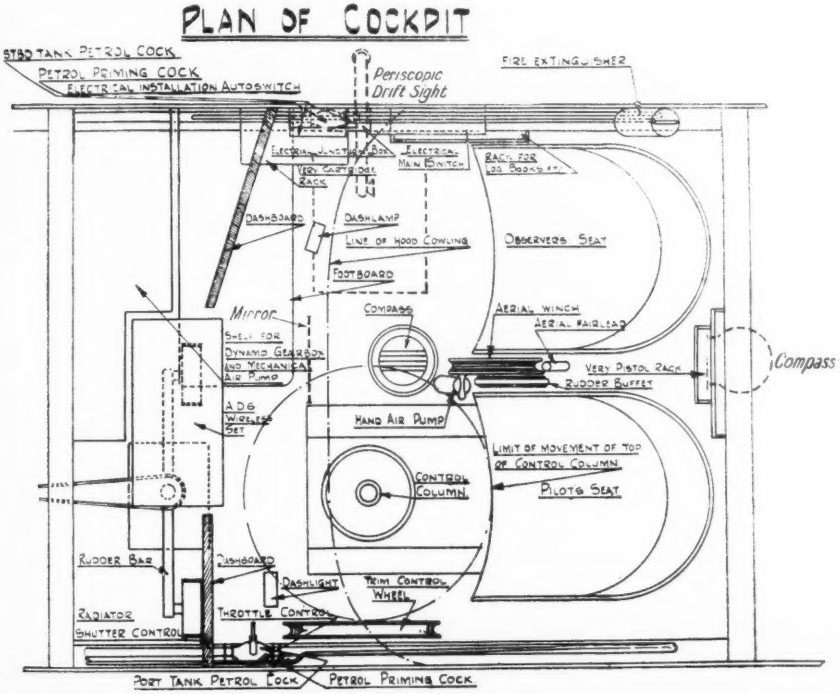


FIG. 12.

pressure gauges and thermometers, with the dashboard slightly inclined so as to be plainly visible from the port seat.

Fig. 12 is a plan of the cockpit. The pilot is placed on the port side, so that he is in the better position to comply with the rules of the air.

The navigator requires room to operate his maps, a clear view of the compass, air speed indicator, altimeter and watch, a clear view out of the cockpit, and a vertical view of the ground.

A small chart table is fitted in front of the starboard seat. The position of the compass is satisfactory from the point of view of accessibility and navigator's view, but is not in the ideal position for the pilot. A position on the dashboard would be too near the engine. The alternative position with the mirror compass is shown. The air speed indicator and altimeter not being of quite the same importance as the compass can be seen sufficiently well from the navigator's seat.

The vertical view of the ground is required for the fitting of a drift indcator. This is usually secured in present day large transport machines where the pilot's cockpit is forward of the leading edge of the bottom plane. The periscopic drift indicator may be fitted immediately in front of the starboard seat.

This arrangement provides all that is required at the present moment for the carriage of a navigator. The main necessity in design is that the cockpit should not be made too cramped.

Conditions Governing the Carriage of Navigators

There are in existence at the present moment certain regulations governing the carriage of navigators on commercial aircraft. They were introduced in the very early days of civil aviation and can only be regarded as provisional. The question has scarcely arisen yet, but it may be assumed that it will do so, as the length of stages flown increases and the nature of the country traversed changes

The matter is under discussion by the International Commission for Aerial Navigation and the following proposals have been made :—

There should be two classes of aerial navigators' certificates, a 1st Class of a high standard including astronomical navigation and kindred subjects, such as meteorology, and a 2nd Class including mainly dead-reckoning and radiogoniometric navigation.

In deciding whether and when a navigator shall be carried on public transport aircraft, it is proposed to differentiate between

(1) Mapped country, such as Europe.
(2) Sea or unsurveyed country.
(3) Night flying.

It is suggested that when flying by day over mapped country no aircraft need carry a separate navigator, but that for distances over 500 kms. (300 miles) the pilot should be qualified as a 2nd class navigator. When flying by day over sea or unsurveyed country, the pilot should be required to hold a 2nd class navigator's licence for flights of greater distance than 160 kms. (100 miles), but for flights longer than 500 kms. a separate 1st class navigator should be carried. For all night flights a qualified navigator should be carried, but on certain well lighted routes, the pilot might hold the navigational qualifications. For night flights over 500 kms. a separate 1st class navigator should be carried.

The proposals with regard to airships are that all the officers of ships of 700,000 cubic feet capacity or greater must be qualified navigators and that at least one officer must be a 1st class navigator. On smaller ships it is suggested that at least one officer should be a 2nd class navigator.

The same type of certificate and general qualifications are necessary for airships as for aeroplane work.

These conditions have been modelled, while bearing in mind the difficulty of navigation in certain conditions and the limitations of different methods, with a view to keeping operating crews as small as possible. It is not possible from the administration point of view to take into account weather conditions, though these admittedly are almost the most important factor.

It remains to consider where the navigators are to come from. There is only one possible source—the pilots of the present. The perfectly logical state of affairs would then develop with the progress of civil aviation, that the junior pilot would fly on the shorter routes where navigation qualifications are not required, the more senior pilots who had qualified as 2nd class navigators would fly the medium length stages, and on the longest flights, when two pilots would no doubt in any case be carried, the senior in charge of the machine would hold the 1st class navigator's certificate required.

Efforts to establish a school of navigation for civil aviation in this country have not been conspicuously successful. There is a navigation school in operation in France run by the Aero Club of France, and supported partly by the State and partly by the trade. A private school also manages to keep going. In France, however, a pilot is required to hold an elementary navigator's certificate for all flights longer than 200 kms.

In this connection and in conclusion it is interesting to refer to Hakluyt's remarks on a similar subject, 100 years after Columbus first sailed across the Atlantic :—

" I have greatly wished there were a Lecture of Navigaton read in this Citie, for the banishing of our former grosse ignorance in Marine causes, and for the increase and generall multiplying of the sea-knowledge in this age, wherein God hath raised so generall a desire in the youth of this Realme to discover all parts of the face of the earth, to this Realme in former ages not knowen."

" . . . . I have thought it not impertinent, to exhibite to the grave and discreet judgements of those which have the chiefe places in the Admiraltie and marine causes of England, Certaine briefe extracts of the orders of the Contractation house of Sivil in Spaine, touching their government in sea-matters; together with the streight and severe examination of pilots and masters before they be admitted to take charge of ships, as well by the Pilot mayor, and brotherhood of ancient Masters, as by the Kings reader of The lecture of the art of Navigation, with the time that they be enjoyned to bee his auditors, and some part of the questions that they are to answere unto. Which if they finde good and beneficial for our seamen, I hope they will gladly imbrace and imitate, or finding out some fitter course of their owne, will seeke to bring such as are of that calling unto better government and more perfection in that most laudable and needfull vocation."

Discussion

Major-General Sir Sefton Brancker, in opening the discussion, congratulated the lecturer on having compressed into a short time so much of interest and importance in aerial navigation.

His experience all pointed to the fact that more navigation would have to be done if air transport was to operate really regularly. The technical side of the Air Ministry were developing machines with stabilisers, and other aids, so that they could fly through fog and clouds, and also at night. It was obvious that a greater knowledge and experience of navigation would be required for this sort of flying. He thought that the French were ahead of this country on this point, perhaps because they had a school of navigation. On one occasion he had left Le Bourget in a British machine at the same time as the French "Goliath," and after an uncomfortable journey flying low under the clouds, arrived some time after the "Goliath," which had had good weather above the

clouds. There was no doubt that it would take much education to break pilots of the idea that flying should be done below the clouds.

In view of his position as British representative on the International Commission of Air Navigation, where this very question was under discussion, he was most anxious to hear the opinions of other people. His own were in agreement with Captain Tymms's.

Mr. BIDDLECOMBE said that it was very difficult to get people to see the necessity for using proper navigational methods. He was glad to see that the lecturer had expressed disapproval of the suggestion of using small lights to mark routes, because he was sure that that sort of thing would only attract pilots to fly low, and flying low meant difficulties should engine or any other trouble arise. He understood that the Americans had come to the same conclusion, and were developing proper methods of navigation.

He was of opinion that the country would be left behind in the future if provision for teaching aerial navigation was not made, and considered that those who believed in the future of aviation ought to make an effort to press the matter.

Major DAVIDSON said that the Post Office Department used lights in the West and not in the East. Over this very flat country the Post Office pilots preferred to fly low in bad weather rather than get up above the clouds where they could not see the ground. In bad weather they often flew as low as fifteen feet above the ground. They could not be persuaded to fly above the clouds unless they were crossing the Rockies. This low flying over the flat country was not dangerous because they were able to land very easily in any direction in case of engine trouble.

In the western and central portions of the United States the country is divided into sections and the section lines are true meridians and parallels. They were very useful guides in flying because a pilot could simply cut the section lines at a constant angle and know he was going in a certain direction despite variations or errors in his magnetic compass.

The Americans had a compass which they thought superior to anything the British have. It is called the Earth Inductor Compass and consists of a small generator driven by a windmill. It is placed well back in the tail of the machine away from local attractions and by turning a small dial on the dashboard the pilot could set off his desired course. The world-flyers liked it very much and relied upon it absolutely when flying over sea. They carried two or three magnetic compasses as well, since they occasionally had trouble with the Earth Inductor Compass, but if the Earth Inductor Compass went wrong it did not show incorrect readings, but cut right out and did not mislead them. The Americans are hopeful that this form of compass will replace the magnetic compass, since it is not affected by local attractions. They had no magnetic compasses so good as the Aperiodic Compass.

He agreed with the lecturer that it was difficult to get a pilot to do the navigating as well as all the other things that were loaded on him.

Squadron Leader A. WRIGHT said that, among so many experienced pilots, he did not wish to say much, but there were three points which he would like to raise. One was the necessity for a map on the scale of eight or ten miles per inch, preferably the latter. The ordinary Ordnance Survey cross-country map in the Service was four miles to the inch, which meant that several maps were wanted for a not very long flight, and these had to be changed during the flight—a most difficult thing to do in the air. This map on the scale of ten miles to the inch, with the features marked in the same way as the four miles to the inch, should be used for longer flights, and the four miles to an inch map could be used at the destination, or when it was necessary to land for refuelling, because the four miles to an inch map gave more detail.

The second point was about the ground speed bar on the drift plate. He could not understand why nearly all the new instruments included the ground speed bar, as the accuracy of the calculation depends on the setting of the slider to the height above ground, which is not always known. The average pilot set his altimeter at zero at his point of departure. If he was flying over country of varying height he had not really an idea of the height of it in relation to that of the point of departure, therefore the ground speed bar was of no use to him at all. He might not know within 500 feet what his real height was, which would mean that his ground speed was going to be wrong by a sixth—it might be ten miles out. The ground speed bar of the instrument is only of value when the height of the aircraft above the ground or sea is known accurately. The errors in connection with the drift plate bar due to human error, tilt and so on, were very small in comparison with the errors due to the unknown height above land or sea level, especially where low altitudes were concerned. This type of error was very obvious when flying between Cairo and Baghdad, where the height of the desert is not known in many places.

A third point was the question of meteorology. In the Service the pilot was generally also the navigator, and to his mind his training in meteorology was almost as important as his training in navigation. If a pilot knew by his synoptic chart what weather to expect on a certain route and he was flying above clouds, he could alter his course accordingly. Without a knowledge of meteorology he can be very much out in his reckoning.

There was a case of a whole flight in Waziristan who had been so anxiously watching their objective that they were surrounded by cloud unawares. Two machines climbed above the clouds and got home safely, while three machines flew below the clouds and crashed badly. If they had all had a sound knowledge of the conditions under which clouds were formed, most probably they would all have chosen the upper route.

Captain Boulnois said that he knew little about aerial navigation, but could speak confidently about map-making. The question of the ideal map for aerial navigation had been going on for years. He thought there was no disagreement that a special type of map was wanted, but the expense had to be thought of. Redrawing a map was an extremely expensive thing to do. Assuming that surveys had already been made, the cost of reproducing the surveys was almost as costly as the surveys themselves. With unlimited money one could produce a perfect series of maps for the whole flying world, but an experimental series at quarter-inch to one-mile scale had cost about £400 a sheet, and as twelve sheets at this scale would be required to cover England alone, the cost of production for this country would be about £4,800. The point was whether there was such a demand for a special type of map to cover this. If not, surely the best course would be to see what could be done with existing maps to keep the costs down. In England they had the four miles to an inch map and the ten miles to an inch, which latter was probably the most suitable scale for civil flying. The International map was on a scale of 1 : 1,000,000, and already covered nearly the whole of Europe and many other countries as well. Those were the only three series and scales they had available. If drawing on new projections was started the cost would increase enormously.

With regard to what it was wanted to show on a map they were all in general agreement, but the question was how not to modify too much the existing maps. The question of showing all prominent landmarks had often been raised, and this of course would be quite simple for any definite route, but only for that route, for one had to remember that in order to establish the prominence of any landmark from the air it had to be viewed from the air. This would mean that reports of such prominence would have to be received and every portion of the ground to be mapped would have to be viewed from the air in order that the

landmarks could be discovered. He thought they could use the existing maps and modify them by printing them in different colours, adding a bit here and so on, and produce maps which would be both practical and cheap. From the map-maker's point of view there was no difficulty in producing different types of maps, but a world map of a special type would not cost less than £400,000.

Captain JOHNSTON said he was very glad to hear a practical navigator admit that no particular method of navigation was infallible. The usual attitude of specialists was to claim infallibility for their particular methods. The practical navigator must be able to adopt all available methods. He need not know the different formulæ for projections, but he must know how to put a map to the use in hand. Similarly with the compass he need not know all the intricate formulæ of magnetic moments or gyroscopes, but what that instrument could do for him when it was wanted.

He was sorry the lecturer had deprecated the value of the great circle, which was of great importance to the navigator on long flights. For instance, on a flight from England to New York, when it might be to advantage to make a choice between the great circle and the rhumb line course. He thought the great circle was just as important to air as to sea navigation.

He was of opinion that too much thought should not be given to placing minute detail on aeronautical maps. The navigator did not want to know whose field or house he had passed over; he was concerned with the distance he was from his objective or some conspicuous place. The really important landmarks and double-track railways were what he wanted shown on the maps.

The lecturer's remarks on different types of compasses were very interesting, and showed great progress in compass construction, but from the airship point of view none of those types was altogether satisfactory, because none of them were gimballed. They were all fixed to the aircraft. In the type which was read by means of a grid it was impossible to read the existing aperiodic compass when it was inclined because one got considerable parallax; similarly with the aperiodic compass with the centesimal scale, and the observer's compass also was not successful for steering by. In airships the compass had to be gimballed because airships often fly 10° by the head or stern for a considerable time. Experimental compasses on the aperiodic system, and gimballed, were now being tried out. It was a pity the lecturer had not seen one of them.

The deviation card the lecturer had shown was an interesting one. From experience in swinging the D.H.34 it was found that the deviation curves had no symmetry at all, but at that time they had their aperiodic compass on the dashboard very close to the magneto. So long as the aeroplane was on the ground it was quite satisfactory, but in the air it did the wildest things imaginable. Soft iron machinery was tried out; theoretically it was all right, but in practice it did not eliminate the disturbances. The curves were possibly more regular, but the values of the deviation were too high and not constant. Builders could not be expected to design their machines round the compass, but they ought to give more consideration than they do to the placing of that important instrument.

He was of opinion that personal errors in astronomical navigation were always greater than the instrumental errors, and were more difficult to eliminate. Therefore experience was vitally necessary. In the Red Sea district, for instance, errors of from ten to fifteen miles were caused by refraction, which an experienced man would know how to regard, but an inexperienced man could be very much misled by them. Navigation was only an aid to one's own commonsense. Experience was what was wanted. He thought it was regrettable that pilots had adopted an antagonistic attitude to navigation. One could get them to listen to arguments in its favour, but they would not put what they had learned into practice. The pilot ought to be the navigator; it was part of his pilot's work.

Flying Officer GILLMAN expressed agreement with the last speaker with regard to the importance of navigation, and thought that one of the reasons why pilots had perhaps neglected it in the past was because of the defective instruments they had had to deal with. He thought the new instruments (mirror compass and periscopic drift sight) would be of great help from the Service point of view, especially as regarded single-seater fighters, for both day and night flying. At the moment the compass fitted to a single-seater fighter could be 25° in error, and was continually changing, so that the pilot could never rely on it and preferred to go by his map only.

He noticed that it had been mentioned that there was no school in England of air navigation, but, while it was true that there was no civil school, there was the Service school at Calshot. It taught air pilotage only.

He raised the question of the lighting of maps and instruments for night flying. At present these had to be read by the help of a torch, which so dazzled the pilot that he found it impossible to see anything outside the machine after using it.

Flight Lieutenant MACKWORTH suggested that the present maps would be much improved by the addition of pictures on the margins of prominent landmarks such as cathedrals, which would enable a pilot to identify towns which were not easily distinguished very often.

He gave details of a scheme for marking the London-Paris route in time of low fog by means of small balloons, which could also be used by night if illuminated. By means of this scheme the pilot could be guided to land, the balloons giving him his height, gliding angle and course to alight in the aerodrome upwind.

Lieutenant-Colonel H. T. TIZARD, before calling upon the lecturer to reply to the discussion, said that the important point was to make the work of the pilot as easy as possible. A pioneer had, of course, to find his way somehow by the best means within his power, but a civilian pilot had a great deal to do, and it was very expensive to have to carry a man to find his way for him. Everyone who drove a motor-car knew the practical value of sign-posts. He thought that "sign-posts" for air routes would be both cheap and practical, and would give pilots confidence. It might be far too expensive to issue special maps, but on organised routes, or for flying over civilised country, indelible marks on the ground to correspond with indications on the map could be provided quite inexpensively.

As regards the future, he agreed with Sir Sefton Brancker that they would have to depend less on low flying, and more on flying above clouds, and he was of opinion that the wireless methods of navigation promised most for the future. By these methods, navigation ought to be made more safe and easy for the pilot; but the sextant would probably always be a useful stand-by for use in emergencies in spite of its relative inaccuracy when used by others than experts.

Captain TYMMS, in his reply to the discussion, said that he wanted first of all to remove any misconception which might have been created by the quoting of the American air mail service as an example. We had great admiration for the work done by the American air mail pilots, and fully recognised the development work done in America by the National Advisory Committee for Aeronautics, particularly in connection with the earth inductor compass. It was in the application of navigation in practice that he believed the American air mail service had not progressed very far, and we should not necessarily therefore model our development on theirs.

He agreed with Squadron Leader Wright that it was quite sound to carry, in addition to the navigation map on a scale of ten miles to an inch, one on a

scale of four miles to an inch covering the destination, but this was a matter which could be dictated by personal choice.

It was difficult to justify the fitting of the ground speed bar, except that it might be occasionally useful, for example over sea, and when it was fitted its use was optional.

He recognised the importance of training in meteorology, and pointed out that civil pilots at present were obliged to pass an oral examination in this subject before being granted Class "B" licences. The proposals with regard to civil navigators' licences included meteorology in the syllabus of examination, the syllabus for first-class certificates being quite a stiff one.

Captain Boulnois had raised the question as to whether there was sufficient demand for special maps. The answer was that there was not at present, but there almost undoubtedly would be some some day, and it was necessary to keep in front rather than behind developments. In the meantime, the only way was to modify existing maps, but he wished to emphasise what precautions were necessary if the international 1/1,000,000 map were used for this purpose.

He admitted that his remarks about the great circle had possibly been ambiguous, but Captain Johnston would find that they were fairly clearly put in the paper. He did not really decry great circle sailing. In fact, it was obvious that it would be a very important factor in airship navigation. He quite agreed that too many small landmarks were not wanted in maps, or at any rate that it was a great mistake in navigation to pay too much attention to them.

For airships, gimballed compasses were absolutely necessary. The conditions for airships were entirely different from those on heavier-than-air machines. He was sorry that he had not thought of illustrating one of the aperiodic gimballed compasses for which Captain Johnston had been largely responsible. Reports on the screening of magnetos showed it to be a promising method of reducing deviation, and he hoped to see some tests carried out with this shortly. He could not agree with Captain Johnston that the personal error with a bubble sextant was greater than the instrumental error. The bubble was affected by accelerations over which the observer had no control. He thought Captain Johnston referred rather to the natural horizon sextant.

He was interested to hear from Flying Officer Gillman that full courses in navigation are again in operation at Calshot. The R.A.F. school at Calshot had not been forgotten, but most of his remarks had reference to civil aviation. F.O. Gillman's account of his experiences with compasses in single-seater fighter machines illustrated the great difficulty of fitting a compass to a single-engined machine.

It would be quite possible to use the margins of maps for pictures of prominent landmarks as suggested by Flight Lieutenant Mackworth. This device had been adopted in the American air route maps for giving plans of landing grounds.

With regard to the suggestion of aerial buoys for navigation in fog, the chief difficulty was found to be, not the navigation, but the landing in foggy weather. As balloons could be used only on organised routes, where directional wireless was already available, there seemed to be no need to incur the extra expense. With regard to landing in fog by the aid of balloons, he preferred to leave this question to the opinion of pilots, but the suggestion was one which had been many times discussed.

The Chairman had made the suggestion that suitable marks on the ground would help to make things easy for pilots. In the south-east of England many towns already had their names marked out on the ground in white chalk. Various systems of marking have been suggested, such as arrows situated on the circumference of a circle pointing towards an aerodrome at the centre. The point about them all was that if the conditions were bad the marks probably would not be

seen at all, so that just when they were wanted they really did not help. When conditions were good, pilots had no difficulty in finding their way without them. The solution which meets every possible set of circumstances is the proper application of the principles of navigation. Though it may seem a formidable subject, all pilots with experience will agree that in any given set of circumstances the practice of navigation eases their task rather than making it more difficult. Proof of this is to be found in the fact that the older and more experienced civil pilots have (in some cases almost unconsciously) developed the simpler rules for themselves and regularly apply them (again, often subconsciously). That this is developed and not instinctive is amply demonstrated by watching the record of a squad of pilots under training, doing their early cross-country flights.

If navigation really made matters more difficult for the pilot, it would stand self-condemned.

He agreed that the development of radiogoniometry should be pressed forward as the best means of fixing position.

The CHAIRMAN, in proposing a hearty vote of thanks to the lecturer, said that those present would agree that they had seldom heard a difficult subject treated in so clear and admirable a manner.

SOME CONSIDERATIONS IN THE DESIGN OF A LIGHT AEROPLANE

BY FLIGHT LIEUTENANT N. COMPER, R.A.F., ASSOCIATE FELLOW.

It became apparent after the light aeroplane competition at Lympne in October, 1923, that the popularisation of the light aeroplane from the civil point of view demanded something more than the single-seater, although, in many respects, the considerations already aimed at and generally achieved must still form a definite controlling factor in design.

Briefly such considerations may be said to be:—

Low initial cost and upkeep.

Immunity from accidents.

Handiness as governed by the small field and garage accommodation at present available to the owner pilot.

It is perhaps obvious that such requirements approach that popular conception of flight—a car with wings—but to-day that ideal is far short of realisation owing to the large overall wing dimensions necessary to support the total weight. Extensive reduction of overall size is definitely limited unless wings of considerably greater optimum lift coefficient are employed than those which are at present popular from a lift drag point of view, bearing in mind that the effective speed range of the craft must not be cut into as would be the case if an inefficient wing section or wing arrangement were adopted.

To take these requirements one by one; low initial cost and upkeep depends on constructional design, the power unit employed and fool-proof characteristics. Immunity from accidents demands a speed range in favour of low stalling speeds —that is light wing loading, effective control at speeds below that of stalling— good vision and full precautions against fire. Handiness embraces folding or similar methods for transport across open country and for storage purposes. Such perhaps represents that civil point of view which in the light of to-day's knowledge shows a clear road for development.

To turn to the Service demands we find that in addition to those qualities already enumerated the designer must pay particular attention to the vital needs associated with the successful instructional machine; for example:—

Similarity to the general types of aeroplane standard for the service, particularly as regards controls.

Freedom from vices although full capability of all voluntary evolutions.

Maximum ease of communication and demonstration between pilot and pupil.

The question of similarity in type definitely shackles the designer in any big expression of originality, and such attractive propositions as the tailless and tail-first aeroplane may be considered as best left out at this stage. Freedom from vices whilst often being considered as a matter of luck can, for the main part, be guarded against without any appreciable loss of efficiency. To bring pupil and instructor into direct touch with each other there can be no better way than by side-by-side seating. This is the obvious method as it does away with undesirable communication by telephone and makes it a simple matter for each occupant to observe the other's actions and movements.

Further, most pilots tend to manœuvre and land their craft from one side only—perhaps in making a general rule it would not be far wrong to say that the average pilot looks out of the left-hand side of the cockpit when landing. This is a custom inbred from their instructional days and one that without doubt does on occasion cause difficulty, for example a customarily left-handed pilot who flies a large aeroplane from the right-hand side. Although this is a small consideration yet it is likely to result in strained or even "written off" undercarriages.

It is not unlikely that such ambidexterity could usefully form part of a pilot's training on a sociable machine. With these points in view the type of light aero-

plane under consideration will require to be a normal tractor monoplane or biplane of straightforward and therefore inexpensive construction with wings that can be folded or strapped to the sides of the fuselage together with a limited tail plane span for transport and garaging purposes. It should have a landing speed not greater than 30 m.p.h., a fair degree of stability and control surfaces sufficiently large to give control at 20 m.p.h. It is here interesting to note that most aeroplanes will fly under control about 10 m.p.h. below their " official " stalling speed, as long as the pilot's control movements are not jerky. This constitutes the well-known " pancake," and is a condition of controlled descent which if confined to ground level offers little risk to the occupants although very detrimental to the present day undercarriage. Continuing, the only real departure from standard practice now left will be an abnormality in relative fuselage width necessary to seat the crew side by side. Here then are certain aims. We can now turn to the finished product : the C.L.A.2, a two-seater dual controlled light aeroplane which, with one reservation concerning power reserve which will be discussed later, it is confidently asserted does fulfil the requirements just enumerated.

As regards the actuality of such requirements the force of the argument can only lie with the pilot instructors. The choice of biplane against monoplane has little to support it and actually was fixed by a belief that it would give a more simple design.

This, therefore, is quite outside our consideration of the moment, although the accompanying charts, which were compiled recently on data obtained from the Lympne competitions of 1923 and 1924, may, perhaps, provide food for thought in connection with the reduction of the total weight of such craft.

The object of these tables is to show that on the light aeroplanes now in existence in this country there is always one weight which can fix the designer's total weight estimate.

Considering both the single-seater monoplane and biplane and the two-seater monoplane and biplane, four different types of each (A,B,C,D) are shown, the types differing only in total weight.

As there are certain weight components which are fixed by the number of the crew, the power unit available, etc., such weights have been tabulated to form what are shown as basic weights.

The structural components will generally form one definite percentage of the total and the percentages shown represent mean figures collected from past light aeroplanes. It will now be seen that by adding the basic weights to the structural weights obtained from these mean percentages, we can observe by comparing these totals with the type totals (column 2 of charts) how far out on the light side or on the heavy side will be the weight budgeting initially employed.

If the actual weights (column 7) come lighter for one type, then the structure has been stressed for too high a total weight and would therefore have been lighter still if a lower total weight had been initially taken for stressing purposes. On the other hand if the actual weights come out heavier, we must assume that our lower estimate will not probably be realised, and consequently, our stressing total weight being on the low side, the actual load factors will be correspondingly decreased.

From these tables it is apparent that there is one type in each set where the percentage totals (column 7) will agree with the estimated totals (column 2) and this particular weight figure well represents the class of light aeroplane to which it refers.

To take for example the two-seater biplanes, type C gives a percentage weight total which lies within six pounds of the 850 lb. estimate and the two-seater monoplane gives 900 lbs. as a likely figure, both of which agree with the average total weights of the successful two-seaters entered for the 1924 competition.

If this latter statement is at all questionable it is because few actual weights are available, but it is not far out to state that most of the entries for this com-

petition were heavier than was shown in the weight estimates published concurrently with the trials.

The overall weight of the Cranwell Light Aeroplane is 890 lbs. (full competition load), that is 40 lbs. in excess of the " correct " 850 lbs., and although the wide fuselage may be taken as responsible for this, yet, in the light of experience gained, it is believed that a second machine could be made to the lower weight.

The wing section employed is the R.A.E.64 propeller section, which without possessing any startling features gives a good compromise in lift/drag characteristics. The big item in drag is naturally the fuselage. The width of this was fixed by the size of the rudder bars, which, owing to the desire for normality in controls, were kept approximately the same size as would be found in the ordinary tandem cockpit arrangement. This permits plenty of seating room as well as giving a width of body which many would think unnecessary; but this, however, is a matter of opinion.

The shape of the fuselage nose and the naked condition of the engine mounted on the extremity of the nose makes full accessibility to the engine possible, and is an endeavour to separate the great body bulk from the small airscrew, and by helping the airflow behind the airscrew a considerable reduction in body drag is probably effected, far more than would be the case if normal streamline features were employed.

Keeping within reasonable limits all control surfaces were made as large as considerations of weight and overall dimensions would permit, with control at very low speeds as the main object.

The undercarriage is so arranged that a very quick pull up is possible on landing owing to the large drag angle given by the body and wings when the tail skid is in contact with the ground, and also because the tail skid takes a greater proportion of the total load than is the usual practice. Also, in the case of the hard usage which is the lot of training machines the undercarriage is very sturdy and easily replaced when the inevitable crash occurs, each " vee " being cut from one piece of multi-ply.

Finally the actual performances of this aeroplane under full competition load should be stated in order that the conclusions arrived at may be based on actual fact rather than on hopeful estimates.

The stalling speed is 30 m.p.h. and here this refers to that speed where, with full engine power, flight is not possible without loss of height.

The maximum speed at ground level is 60 m.p.h. This gives admittedly a speed range of no marked brilliance but, as it tallies well with the performance predictions and is exactly what would be generally expected of a sociable two-seater flown with an airscrew, which, owing to high engine revolutions only gives 55 per cent. of the maximum 30 h.p. available, it is obvious that the root of the speed deficiency is the result of a pronounced lack of power.

Then again assuming this speed range was considered sufficient for general training purposes, there are few pilots who would be content to fly with consistently no power reserve. In fact, such limits should be found anywhere but on a training machine. If, however, the power limit of the Lympne competitions is the cruising power of to-day, that is to say we have 40 h.p. for taking off, getting height and general emergency, such an aeroplane should truly justify itself as a cheap and economical training machine without having to resort to the present day heavier and therefore uneconomical types with engines which range from 60 to 100 h.p.

In conclusion, for corroboration of these facts we can turn to those who have seen the controllability, handiness and general behaviour of these light two-seaters, possessing as they do such characteristics as 30 miles to the gallon in petrol consumption, complete control at 20 m.p.h. involving unusually good forced landing qualities, and an initial cost which simple construction and a small power unit can bring to a really low figure.

DETERMINATION OF w=AVERAGE TYPE WEIGHT.

Example: Two-seater biplanes.

$$w = 510 + 0.1974\,w + 0.1785\,w + 0.0311\,w$$
$$w - 0.407\,w = 510$$
$$w = 860 \text{ lbs.}$$

BIPLANE TWO-SEATER.

1 Machine Type.	2 Initial total weight as basis for design.	3 Constant Basic weights as estimated.	4 Wing weights as 19.74 per cent. of total weight (col. 2).	5 Body weight as 17.85 per cent. of total weight (column 2).	6 Empennage weight as 3.11 per cent. of total weight (col. 2).	7 Total weights (basic weights plus individual per cent. weights).
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
A	950	510	187.53	169.57	29.54	897
B	900	510	177.66	160.65	27.99	876
C	850	510	167.79	151.72	26.43	856
D	800	510	157.92	142.8	24.88	836
E	750	510	148.05	133.87	23.33	815

MONOPLANE TWO-SEATER.

1 Machine Type	2 Initial total weight as basis for design.	3 Constant basic weights as estimated.	4 Wing weights as 19.82 per cent. of total weight (col. 2).	5 Body weight as 22.0 per cent. of total weight (column 2).	6 Empennage weight as 2.87 per cent. of total weight (col. 2).	7 Total weights (basic weights plus individual per cent. weights).
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
A	950	510	188.29	209	27.26	934
B	900	510	178.38	198	25.83	912
C	850	510	168.47	187	24.395	890
D	800	510	158.56	176	22.960	868
E	750	510	148.65	165	21.52	846

Column 2 represents fictitious weights on which the percentages in columns 4, 5, 6 and 7 are based.

Column 3 represents constant basic weights made up as follows:—

Engine	90 lbs.
Pilot	170 ,,
Passenger...	170 ,,
Controls	12 ,,
Petrol tank and fuel	46 ,,
Instruments	8 ,,
Engine mounting	8 ,,
Airscrew	6 ,,
Total	510 ,,

Columns 4, 5 and 6 represent component weights as mean percentages of the total weights (based on data from present day light aeroplane).

Column 7 represents the total weights from columns 3, 4, 5 and 6.

BIPLANE SINGLE-SEATER.

1 Machine Type.	2 Initial total weight as basis for design.	3 Constant basic weight as estimated.	4 Wing weights as 19.07 per cent. of total weight (col. 2).	5 Body weight as 20.13 per cent. of total weight (col. 2).	6 Empennage weight as 3.07 per cent. of total weight (col. 2).	7 Total weight (basic weight plus individual per cent. weights).
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
A	600	320	114.42	120.78	18.42	574
B	550	320	104.88	110.66	16.88	552
C	500	320	95.35	100.6	15.35	531
D	450	320	85.81	90.58	13.81	510

MONOPLANE SINGLE-SEATER.

1 Machine Type.	2 Initial total weight as basis for design.	3 Constant basic weight as estimated.	4 Wing weights as 22.07 per cent. of total weight (col. 2).	5 Body weight as 17.76 per cent. of total weight (col. 2).	6 Empennage weight as 3.61 per cent. of total weight (col. 2).	7 Total weight (basic weight plus individual per cent. weights).
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
A	600	320	132.42	106.56	21.66	581
B	550	320	121.38	97.68	19.85	559
C	500	320	110.3	88.88	18.05	537
D	450	320	99.31	79.92	16.24	515

Column 2 represents fictitious weights on which the percentages in columns 4, 5, 6 and 7 are based.

Column 3 represents constant basic weights made up as follows:—

Engine	90 lbs.
Pilot	170 ,,
Controls	7 ,,
Petrol tank and fuel	31 ,,
Instruments	8 ,,
Engine mounting	8 ,,
Airscrew	6 ,,
Total	320 ,,

Columns 4, 5 and 6 represent component weights as mean percentages of the total weights (based on data from present day light aeroplane).

Column 7 represents the total weights from columns 3, 4, 5 and 6.

NOTE.—Engine weight is that of the Cherub. Therefore all these single-seaters must be considered as being Cherub engined.

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